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WEED CONTROL

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WEED CONTROL[1]

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INTRODUCTION[6]

CALIFORNIA AGRICULTURE with its diversity of crops, soil types, and climatic conditions presents problems that challenge not only the farmer but also the trained agriculturist and scientist. Among these problems the control of weeds claims more and more attention. Even now, apparently too little time and effort are spent in combating these pests.

Weeds, being inconspicuous in their habits, often go unnoticed; after having been present a few years they are frequently taken for granted. This very characteristic, however, is dangerous, tending toward neglect in their control and allowing their wide dissemination before the danger is realized. An example is the Klamath weed (St. Johnswort), which spreads over approximately 100,000 acres of range land in this state before organized control was started.

The situation is not hopeless, however, for many California growers have so effectively combated weeds that now their fields and ranges are clean, their products uncontaminated, and their losses from weeds reduced to a minimum. The time and labor expended annually for weed control can be largely reduced if available methods are put to use.

With intensification and concentration of agriculture upon the more productive soils, pest control is increasingly necessary. Not only is individual effort demanded, but coöperation by community and state agencies is needed to curb weeds.

Two examples show how wide may be the influence of weeds and how complex the control program. Leafhoppers. which carry the curly-top virus of the sugar beet and the western yellow blight of tomato, live over on various summer and fall annuals in the south San Joaquin Valley but do their damage in the Salinas Valley, the lower Sacramento and upper San Joaquin valleys, and the intervening delta regions. Livestock,

[1] This publication is a revision of and supersedes Extension Circular 54, "The Control of Weeds," by W. S. Ball, B. A. Madson, and W. W. Robbins.

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[6] A list of all weeds mentioned in this circular, giving both common and scientific names, is found at the back of this publication.

pasturing during winter and spring in the Klamath-weed-infested ranges of Humboldt County, often spend the summer in Trinity National Forest or the foothills of the upper Sacramento Valley.

Eradication of established noxious weeds is usually difficult. Operations must be prompt and persistent. Often, for complete eradication, high initial costs are justified. The projects on camel thorn and artichoke thistle now being supervised by the State Department of Agriculture will, if successfully completed, mark an epoch in the history of weed control. If allowed to spread, these two weeds would undoubtedly cost the state many times the total expense of eradication. But many of our noxious perennials are here to stay, and only through adequate control measures may we continue to farm the infested areas. According to experiments in progress, at least some of our deep-rooted perennials may be controlled by methods that allow the simultaneous growing of crops and incur little actual loss. Cultural methods, cropping sequences, and rotation programs offer much promise in this field. As such methods are undoubtedly the most practical for the average farmer, it is to be hoped that adequate investigational work on this phase of weed control will soon be provided.

This circular attempts to picture the weed problem in California, together with the most practical and promising remedies now employed. Obviously some methods have not been sufficiently tried. We are not ready to lay down arbitrary rules for controlling any one weed or group of weeds. The different species, in fact, are so unlike in their characteristics and habits, the climatic and soil conditions under which they grow differ so greatly, and the effects of weeds on the various crops with their different cultural requirements vary so much that methods universally applicable will probably never be devised. The general principles presented and the specific cases cited should, however, be useful. This circular should answer many questions submitted almost daily to the College of Agriculture and the State Department of Agriculture.

LOSSES CAUSED BY WEEDS

There are four groups of agricultural pests: (1) animal diseases, (2) plant diseases, (3) insects, rodents, and predatory animals, and (4) weeds. As shown by a recent report of the Agricultural Service Department Committee, United States Chamber of Commerce, the annual losses from weeds considerably exceed the combined losses of the other three groups. This same organization listed thirty important items of waste on American farms; soil erosion ranked first and weeds second.

Few realize what a burden weeds add to human existence. The production of almost all crops is largely a battle with weeds. The preparation

of many products of the soil for human consumption involves the elimination of weeds or their effects. Weeds cause losses in many ways:

1. They compete seriously with crops for plant food, moisture, and light.

2. They increase the labor necessary for crop production.

3. They increase the cost of preparing many crop products for consumption.

4. They impair the quality and destroy or reduce the value of many products of the soil.

5. They harbor insects and fungus pests destructive or injurious to economic plants.

6. They are sometimes poisonous and may endanger the health or life of man and animals.

Weeds in the United States have been said to levy, in one way or another, an annual tax on agriculture and industry of about three billion dollars. Though no estimate has been made of the weed tax in California, it is probably at least proportional to that of the country as a whole—a minimum of sixty million dollars, the larger portion of which falls on agriculture. Indiana in 1920 estimated its average annual loss through weeds at $210 per farm; Wisconsin in 1927 at $244.

Loss of Plant Food, Water, and Light.—Probably the heaviest loss by weeds, especially in California, results from their competition with crops for plant food, moisture, and light. The crop-producing power of our agricultural soil is usually limited either by the moisture, obtained frequently only at high cost, or by the plant food available. When the crop must share this limited supply with weeds, lower yields result.

Upon unirrigated land, water is usually the limiting factor in crop production; poor yields or total crop failures often occur because the water supply has been exhausted before the crop matures. Weeds may contribute greatly to this condition. Obviously, grain fields infested with wild oats, wild mustard, wild radish, or other weeds will have their yields reduced, partly, perhaps, through shading and loss of plant foods, but chiefly through the use of water by the weeds. In fact, one main reason for cultivating is that it eliminates the undesirable plant growth which, except in the first few inches, causes most of the loss of water.

On irrigated land, competition may be keener for plant food than for water; but the effect is just as striking. For example, alfalfa infested with foxtail or Bermuda grass, usually makes but a slow, weak growth. When the weeds are removed by cultivation or burning, the alfalfa plants are immediately stimulated. In young orchards infested with morning-glory, the trees are often noticeably affected by weeds.

That morning-glory, creeping mallow, and other perennials depress or prevent the growth of summer crops like sorghum, corn, cotton, and beans is too well known to need discussion.

Increased Cost of Labor and Equipment.—The labor and equipment necessary to keep weeds in check constitutes another tax upon the farm income. The main reasons for cultivating annual crops are the preparation of the land for planting and the keeping down of weed growth. In vineyards and orchards the principal, if not the sole, purpose of cultivation is weed control. The average cost of such tillage on cultivated lands has been estimated at one-twelfth the value of the crop or, for California, about $40,000,000 annually. These figures, however, do not include the very considerable expense of eradicating weeds in ditches, roadways, and waste lands near the cultivated areas, nor the public money expended specifically on campaigns against the more noxious weeds.

Also chargeable against weeds is an enormous investment in equipment. Almost every farm possesses one or more implements used primarily for weed control.

Increased Cost of Preparing Crop Products for Consumption.—After the crop is grown, weed contamination may involve further expense in handling and processing, especially with the seed crops and with cereals such as rice, barley, and wheat. Millers must install costly equipment for removing weed seeds and other material of weedy origin.

Most seed crops grown in California are contaminated with weed seed. In fact, one main reason for the relatively high price to the farmer is that such seed, as grown, is usually foul with weeds, which the dealer must remove by expensive methods.

An excellent example of the extent to which weeds increase the handling costs may be found in our cereal crops. The average annual production of wheat, oats, barley, and rice in California is about 1,444,000 tons, with an average dockage of well over one per cent, consisting mostly of weed seed or material of weedy origin. In the harvesting and marketing of these crops, therefore, more than 11,000 tons of weed seeds and residue must be handled and transported. Further, as already indicated, much of the cleaning cost to which most cereals must be subjected should be charged against weeds.

Impaired Quality of Farm Products.—Weed contamination of many crops reduces their quality and market value. Weedy alfalfa hay, for example, brings from $1.00 to $2.50 less a ton. Since much of the first cutting and part of the second are liable to be weedy, at least one-fifth of the crop may be assumed to contain objectionable quantities of weeds. With an average reduction in value of $1.50 a ton, the annual loss to the alfalfa industry in California is approximately $1,200,000. Some

weeds are more objectionable than others. For example, hay infested with puncture vine may be practically worthless; in fact, many counties prohibit its importation.

The market value of wheat may be greatly reduced by the presence of certain weeds. Even a few seeds of sour clover, for example, will render a sack of wheat unfit for milling.

Harboring of Insect and Fungus Pests.—Weeds harbor many fungus and bacterial diseases and many insect pests. Thus they aid in propagating such crop enemies, which they render more destructive and more difficult to control. The bacterial organism causing bean blight lives on some of the wild legumes; the organism causing blackleg of cabbage also thrives on wild mustard. Certain wild mustards may harbor the fungus that causes clubroot in cabbage. The downy mildew of lettuce is caused by a fungus that may live on several weeds belonging to the composite family, including prickly lettuce and sow thistle. Harris and Stout[7] list 29 species of California weeds known to be hosts for one or more virus diseases; aster yellows, for example, is spread by the six-spotted leafhopper, an insect common on several wild hosts, especially the broad-leaved plantain. The curly top of sugar beets, another virus disease, is spread from wild hosts to cultivated plants by the beet leafhopper; its virus has been found present in California in 19 weeds, especially *Atriplex* species and Russian thistle. Lockwood[8] cites the following insects that hibernate in trash and weeds: grape leafhopper, apple leafhopper, field crickets, tarnished plant bug, big-eyed bug, and harlequin cabbage bug. In addition, several important insect pests build up their numbers on weeds and migrate to commercial crops. *Lactuca* species will act as a host to the bean thrips; Russian thistle not only to the beet leafhopper mentioned above, but also to the western beet leaf beetle and the young of the tiger moth; wild aster to the vegetable weevil; shepherd's purse to such pests as the sugar-beet leafhopper, the clover aphid, the leaf-curl plum aphid, the cotton or melon aphid, the bean aphid, the cabbage aphid, and the green peach aphid; lamb's-quarters to the cottony cushion scale, the harlequin cabbage bug, the banded flea beetle, the beet and spinach-leaf miner, and the apple skin worm. *Rumex* species are hosts to the citrus thrips, the grape leafhopper, the apple leafhopper, the sugar-beet wireworm, the strawberry-root weevil, and several species of destructive aphids; Jimson weed to the red spider, the cotton or melon aphid, the potato flea beetle, the tomato

[7] Harris, M. R., and G. L. Stout. Weeds as a factor in the spread of plant diseases in California. California State Dept. Agr. Mo. Bul. **22(6)**:273–277. 1933.

[8] Lockwood, Stewart. The relation of weeds to insect pests. California State Dept. Agr. Mo. Bul. **22(6)**:279–282. 1933.

sphinx, and the potato-tuber moth; several species of plantain to the rosy apple aphid, the cotton or melon aphid, the tarnished plant bug, the potato flea beetle, and the serpentine leaf miner; species of wild mustard, for a time at least, to the sugar-beet leafhopper, the grape leafhopper, black grass bug, the harlequin cabbage bug, and other injurious insects; wild morning-glory to many crop pests, including the common red spider, several species of thrips, the cotton or melon aphid, and the soft brown scale; and lupine to the pod borer, so destructive to baby lima beans. J. C. Elmore, of the United States Bureau of Entomology, states that in the pepper-growing districts of southern California approximately 85 per cent of the first weevil infestations in the spring originate from one species of nightshade (*Solanum douglasii*), which is a host to the pepper weevil, especially in winter. This weed, therefore, should be eradicated from areas devoted to pepper growing. Nematodes and grasshoppers, destructive to many crop plants, live and multiply on weeds. Though other examples might be cited, those given indicate how weeds assist insect pests. In fact, if uneconomic plants could be eliminated, some of our worst crop pests could be easily controlled.

Injury to Livestock and Human Beings.—Many domestic animals are lost annually from weed poisoning. The most important poisonous weeds, such as larkspur, water hemlock, whorled milkweed, Klamath weed, and death camas, occur extensively on some ranges, under conditions difficult to control. On cultivated lands and in pastures seeded to cultivated plants, many animals are lost through their owners' failure to eradicate poisonous weeds. Certain species of lupine, poisonous when in seed, cause annual losses of sheep.

The health of human beings may also be affected. Deaths occasionally occur from the eating of poisonous seeds, berries, or tubers. Poison oak causes much suffering and distress, and many victims of hay fever can trace their affliction to the pollen of weedy plants.

INTRODUCTION AND SPREAD OF WEEDS

Weeds as we know them today were no problem in the lives of early California settlers. They were, with few exceptions, introduced into this country with the settlers and their crops. To this day, in fact, specific crops tend to have their special pests; and, with the introduction of new crops, new weeds are certain to occur. Wild oats and many weedy range grasses, apparently, arrived with the Spanish invaders, probably in hay accompanying livestock. Some of these weedy annuals were so thrifty and so prolific in seeding that they have practically supplanted the native vegetation of our foothill range areas.

With the westward march of intensive agriculture came the weeds

that had attended its development for ages. The pigweeds, thistles, morning-glories, and others came with the American farmer and have not only persisted to tax his labors but thrived as in no other situation. In the deep alluvial soils and temperate climate of California many weed species find better conditions than in their native lands. They have tended, consequently, to drive out economic plants and have resisted the control measures effective in the East and in Europe.

The introduction of new weeds has continued up to the present, and only constant vigilance can check their establishment and spread. Artichoke thistle was first brought in as a vegetable, restricted to a few gardens. Escaping, it has covered thousands of acres of valuable range land in Solano and other Bay counties. Camel thorn, an extremely pernicious weed, was first brought into a southern county, presumably from southwestern Asia in Turkestan alfalfa seed. From this small start it spread to ten California counties, infesting approximately 600 acres. At present Marlahan mustard, or dyer's woad, a biennial weed from Europe, is confined to Scott Valley in Siskiyou County. Austrian field cress, a perennial, also from Europe, is limited to a region at the headwaters of the south fork of the Pit River in Modoc County. Many of the early infestations were limited in area and, by proper handling, could have been eliminated; but ignorance, indifference, neglect, or improper methods have permitted most of them to spread, till today some are beyond hope of eradication.

If an infestation involves a small patch of a very noxious weed, especially a new introduction, strenuous methods and considerable expense are justified in preventing that weed from gaining a foothold. An expense that might be inordinate if required over a larger territory becomes, in such an emergency, highly practical.

To prevent the introduction and spread of new noxious weeds in California requires vigilance, not only by quarantine officials, county agricultural commissioners, and farm advisors, but also by growers. When new weeds are found, prompt and concerted action should be taken. If eradication is too difficult for the individual, then county and state should coöperate. All infested areas should be adequately marked and periodically inspected to insure complete eradication.

Impure Commercial Seeds.—Probably the most common and effective means of introducing weeds is the *sale and distribution of impure commercial seeds.* Hoary-cress and Russian-knapweed infestations in many localities in California can be traced to impure Turkestan alfalfa seed brought in during the World War. These two pests are now so widely distributed that there seems to be little hope of eradicating them.

During the winter of 1927–28 many consignments of Sudan grass seed

grown in Texas and Oklahoma were shipped into California. The State Seed Laboratory of the Bureau of Field Crops, California Department of Agriculture, noted a rapid increase in the percentage of Johnson grass seed beginning with the receipt of samples of this imported Sudan grass seed. The high percentage of Johnson grass continued through

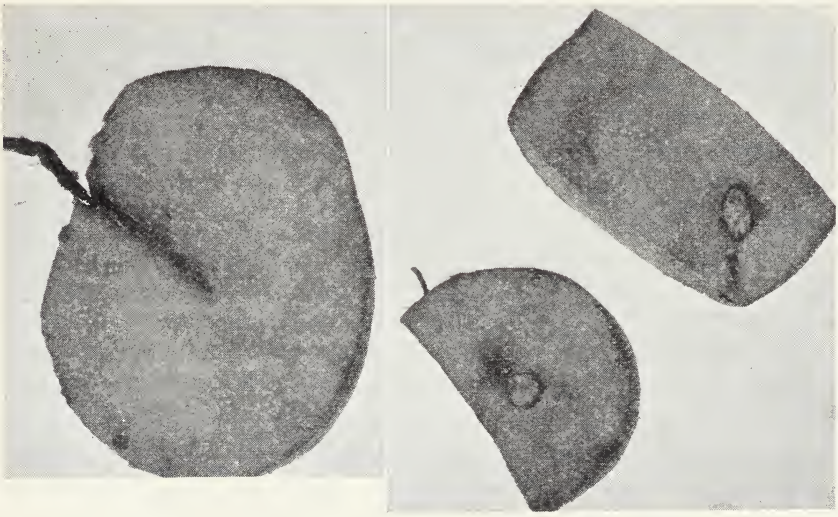

Fig. 1.—Left, rhizome of nut grass penetrating a potato; right, nutlets formed within a potato.

1929 in samples containing typical California weed seeds, indicating many new infestations of this noxious perennial. These examples illustrate the danger of noxious weed seeds that are all too prevalent in unclean commercial seed submitted for analysis.

According to the State Seed Laboratory, alfalfa seed may contain the seeds of barnyard or water grass, dodder, Russian thistle, creeping mallow, yellow star thistle, Johnson grass, morning-glory, bull thistle, Russian knapweed, and hoary cress. Found in barley are yellow star thistle, morning-glory, blessed thistle, barnyard grass, and Johnson grass. Seed oats and wheat may contain these same impurities. In Sudan grass the common weed seeds were barnyard grass, morning-glory, Russian thistle, Johnson grass, and yellow star thistle.

Though these cases were observed by the Seed Laboratory, the exchange of seed from farmer to farmer usually involves inferior grades never submitted for analysis. This uncontrolled sale largely explains the thousands of acres of morning-glory, yellow star thistle, Russian knapweed, and other noxious weeds in California today.

A new means of weed dissemination has recently been noted by the

State Department of Agriculture. While seed potatoes from the Delta region were being planted at Shafter in the south San Joaquin Valley, a worker called the grower's attention to some foreign bodies in the cut seed pieces. The bodies turned out to be nutlets of nut grass (*Cyperus rotundus*), a weed not prevalent in that region (fig. 1).

Federal legislation regarding weed introduction is not adequate properly to protect our agricultural lands. The present California seed law, for instance, allows a tolerance of 89 weed seeds per pound in clover and alfalfa without special labeling. Almost all commercial seed is allowed certain tolerances, any of which are sufficient to permit scattered infestations.

Weed Seeds in Feed, Packing, and Gravel.—Though the practices described above are dangerous, other means of dissemination are equally offensive. Weeds are often introduced in hay, in the packing about trees, in various feedstuffs, and in dirt, sand, or gravel used in construction. During transportation these materials are often scattered along the way, as by the loss of hay from trucks, the kicking of bedding from stock cars, the passage of weed seed through the digestive tracts of animals, and the scattering of manure, gravel, and sand. Puncture-vine and camel-thorn seed can pass unharmed through farm animals. One dairyman, having grazed his animals in a pasture infested with camel thorn, later moved them to the foothills. Their path was marked by scattered infestations of camel-thorn seedlings. Another stockman purchased several loads of hay contaminated with hoary cress. He fed this by scattering it on his own clean range. Hundreds of dollars were later spent in eradicating the resultant infestations.

Other Means of Conveyance.—Weed seeds are often distributed in mud and dirt on the feet of animals or the wheels of vehicles; in soil adhering to plows, cultivators, and other implements; and, within recent years, on the rubber tires of automobiles and airplanes. All kinds of harvesting machinery may carry weeds from farm to farm, particularly the combined harvester, which has spread many pests in California grain fields.

Disposal of Screenings.—The disposal of screenings from seed-cleaning establishments is a matter of grave concern. In the cleaning of commercial seed large amounts of weed seeds are accumulated, and their disposal often becomes a problem. Although burning or fine grinding is the only proper procedure, some unscrupulous dealers sell this material to sheep or cattle growers for feed, or dump it into streams. Seedsmen who tell the farmer at the front door to sow clean seed will sell screenings through the back door to sheepmen, who dump them out on the open range. Sheep thus fed may later be driven for miles through farming

areas and into the hills on summer ranges. No more perfect means of spreading weeds could be devised.

Seed-cleaning establishments have been known to dump their screenings into the Sacramento River, to be carried down stream and spread by irrigation. Whether perpetrated through ignorance or malice, such practices should be forbidden by law and prevented wherever supervision is possible.

The Seed Committee of the State Agricultural Commissioners' Association attempted to determine how objectionable the seed screenings are and how effectively the present grinding methods destroy weed seeds. Samples of screenings, ground and unground, collected by county agricultural commissioners, yielded the following information: Nine samples from alfalfa all contained weed seeds. These 9 samples contained 45 different plant species—mostly weeds. A large-seeded alfalfa dodder was present to the extent of 344 seeds per pound of sample, Russian thistle 27, common field dodder 333. Also found in quantity were Bermuda grass, yellow star thistle, sow thistle, chicory, seaside heliotrope, and creeping mallow.

Eighteen samples of mixed screenings from wheat, barley, and oats contained 77 different plant species—mostly weeds. Johnson grass sometimes occurred in numbers as high as 8,175 seeds per pound of sample, morning-glory 882, yellow star thistle 2,178, and cat's-ear 1,200. Also present were chicory, sow thistle, spiny sow thistle, milk thistle, and seaside heliotrope.

One sample of sorghum screenings averaged 18 seeds of Johnson grass and 45 seeds of puncture vine per pound of sample, and showed a total of 16 different weed species.

Of the ground screening samples examined, 11 had been run either through a bur type grinder or a Hammermill. Of these 11 samples, 81 per cent showed the presence of weed seeds. Thirty-one different plant species, almost all weeds, were found in the ground material, having actually gone through the grinding process without visible injury.

WEED CHARACTERISTICS

Of the countless plants in the world, relatively few are weeds. Most of our native plants do not have weed characteristics; they do not spread from adjacent hills and valleys to cultivated areas and establish themselves as pests. But the world contains some plants with pernicious characteristics: they tend to grow where not wanted; they resist man's attack; they may survive frost, high temperature, and drought; they can grow under varying soil and climatic conditions; they produce enormous numbers of seeds that may live for years in the soil; and they usually

multiply and spread rapidly. Of course, no one plant necessarily has all these undesirable characteristics; but it may have enough to become a pest. Any plant that seeds prolifically, or reproduces vegetatively from underground parts, or is poisonous to livestock or human beings, or causes mechanical injury, may become a *noxious weed*. Furthermore, a weed from one locality may not be a weed in another section with different soil and climatic conditions. Johnson grass, for example, is noxious only where winters are mild, and Klamath weed where the rainfall is relatively high.

Annual weeds must reëstablish themselves each year; to survive they must have a means of perpetuation. Most of these pests either produce enormous numbers of seeds or have some effective way of spreading. For example, certain individual tumbleweeds have been known to produce over a million seeds; and the common annuals usually produce many thousands.

Some weeds are adapted for dispersal by wind, by water, or by animals. The seeds of thistles, milkweeds, dandelions, sow thistles, willow, and wild lettuce have feather-like or cottony attachments that enable them to be blown about. Many weed seeds will float on water; in California irrigation is known to be an important means of spreading them. One of the writers, working in Colorado, found in 156 weed-seed catches from three different irrigation ditches a total of 81 different species, those most frequently met with being prostrate pigweed, tall pigweed, sedge, lamb's-quarters, tall marsh elder, doorweed, black bindweed, curled dock, and dandelion. The seeds passing a given point on a 12-foot ditch during a 24-hour period may number several millions. Early irrigation waters were found to be most heavily loaded with weed seeds, which were often observed to rest during the nonirrigating season in the mud of the ditch. Ditch banks, apparently, are more to be feared than roadsides as effective sources of infestation.

The seeds of numerous weeds such as sandbur, puncture vine, cocklebur, and beggar-ticks attach themselves by barbs or hooked prickles to the hair or wool of animals, or the clothing of man, and are thus carried from place to place.

The noxious perennials spread not only by seed but by roots and rootstocks. Although vegetative spread of undisturbed infestations is relatively slow, plows, harrows, and cultivators dragged through these weeds may carry seeds and portions of the underground organs rapidly over the field, so that the areas soon increase.

Cultural operations as a means of weed dissemination are often overlooked by farmers. In the clean cultivation of morning-glory, Johnson grass, and similar perennials, a very satisfactory cleanup has often been

followed by reinfestation by seedlings, and the labor mostly lost. Often, in fact, large increases in the area infested may follow this practice.

Many seeds retain their vitality for years, especially when buried in the soil. As experiments have shown, the seeds of shepherd's purse, mustard, purslane, pigeon grass, pigweed, mayweed, dock, and chickweed may survive thus for more than 30 years. Prickly pigweed and morning-glory seed live 25 years or more; mallow over 5 years; ragweed, corncockle, cheat, wild oats, and plantain, from 1 to 5 years. Plowing may turn weed seeds under, placing them at depths where the soil atmosphere is unsuited for germination; then, after many years, another plowing brings them to the surface where they germinate. Thus a field that has long been relatively free may suddenly develop a crop of weeds. The seeds of wild oats, tall pigweed, cocklebur, and others seldom germinate the year they are shed, apparently requiring a rest period in the soil. Others, like puncture vine, have hard coats that must undergo a certain amount of decay before germination.

PRINCIPLES OF WEED CONTROL

The methods used in controlling any weed must be related to its habits of growth and reproduction. Since these vary widely, as already indicated, control practices differ. The first problem, always, is to determine the mode of attack best suited to the weed and to the conditions in question. Sound judgment is needed for often success depends upon adapting the methods to the situation.

Annuals.—Annual weeds live but one year; they produce seed but once and then die down entirely, root and all. Having no parts underground by means of which they can spread, they propagate themselves by seeds alone. Obviously, all methods of controlling them have one principal object—*the prevention of seeding*—which may be attained by mowing, cultivating, burning, or spraying. If seed production is consistently prevented over a series of years, and if the introduction of weed seeds from neighboring areas is largely eliminated, the annual weed population will gradually decrease. Of course, weed seeds of many annuals may live for years in the soil and may then be brought by cultural operations to the surface, where conditions for their growth are favorable. The germination of such seeds should be encouraged by irrigation or cultivation before or soon after the crop is planted, to insure killing of the young plants before they injure the crop. Annuals in the early stages are easily and cheaply destroyed by cultivation, plowing, or chemicals; and, once the top has been killed, the root has no power of rejuvenation.

Summer and *winter annuals* differ considerably in their habits. The

seeds of summer annuals germinate in the spring; and the plants grow to maturity during the same season, develop a crop of seeds, and die during the winter. Shallow cultivation and sprays, either oil or acid, afford the best control. It is to check summer annuals that an intertilled summer crop is usually placed in a crop-rotation plan.

Winter annuals usually start in the fall or early winter when soil-moisture conditions are favorable. The young plants live throughout the winter in a vegetative condition, often forming a rosette-like growth. In the spring they grow rapidly, flower, and produce seed. Such plants are more difficult to control in California. The seeds usually germinate throughout the winter; and shallow cultivation, to be effective, would have to be repeated several times—a procedure often impossible during the rainy season. Two effective methods, however, are available.

The first method is plowing. If plowed under fairly early in the spring, these weeds are effectively controlled, leaving the land free for crops. Plowing which is done primarily for the control of annual weeds should be shallow, in order that seeds be kept in the surface layers of soil where they will germinate readily. Spring plowing is common practice in California, both in cereal production and in preparing the land for later summer crops. In cereal production a good job of plowing often means the difference between a clean, heavy crop and a weedy unprofitable one.

The second means of checking winter annuals, principally used in growing cereals, is a selective spray such as sulfuric acid. This method will be described in detail in the next section.

Annuals often grow luxuriantly during the mild winters in California and are sometimes used for pasturage. In this case they are usually plowed under in the spring, and they serve the two-fold purpose of providing green feed for cattle or sheep and a soiling crop for the land. They should be turned under before seed is produced, and the plowing should be clean and thorough. Annuals are similarly used in orchards, providing a valuable covercrop at minimum cost. Where used in this way, they are perpetuated by allowing the seeds to ripen before plowing. This practice always presents the hazard of severe competition for moisture if irrigation water is not available, and it also may menace surrounding fields if seeds scatter. Where such a program is followed, the orchardist should be extremely careful that noxious perennials do not invade his land and spread undetected. Great caution should also be exercised in the planting of screenings for covercrop production.

Although mowing will prevent annual weeds from seeding, some species, such as wild lettuce and wild radish, will send up new shoots from buds in the axils of the lower leaves and may produce a second crop of flowers and seed. Such operations as mowing and spraying must

be done at the proper time; delay may mean failure. The easiest way to dispose of annual weeds is to kill them in their early stages.

Common California annuals are mustards, wild radish, tumbleweed, pigweeds, wild oats, shepherd's purse, barnyard grass, chess or cheat, lamb's-quarters, Russian thistle, puncture vine, dodder, spring sow thistle, yellow star thistle, sunflower, cocklebur, and crab grass.

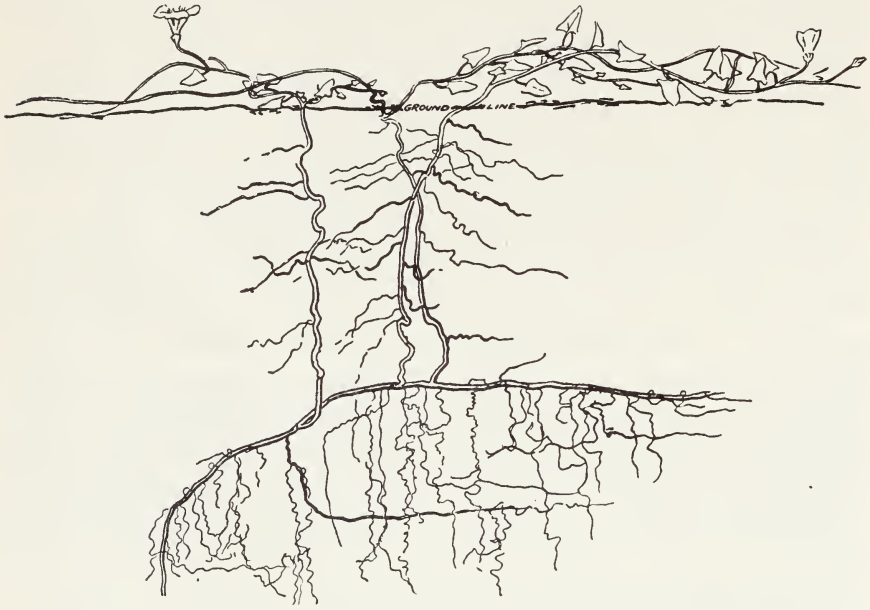

Fig. 2.—Showing the distribution in the soil of the roots and rootstocks of the morning-glory plant.

Biennials.—A biennial weed lives for two years, passing through the first year in a low rosette form and producing seed the second summer. In California the biennials do not form a distinct or important group. Many weeds that are annuals in regions of freezing winters have a biennial habit in this state. True biennials are few, examples being purple star thistle and burdock. They are controlled like annuals, the treatment being made during the first year.

Perennials.—The most troublesome weeds are perennials, which require special methods and systematic, painstaking endeavor for control. Plants in this group, as contrasted with annuals and biennials, live three years or more and spread not only by seed but also by underground roots or stems.

Perennials fall into three classes, according to their methods of reproduction:

The simple perennials have either a large taproot, like the dandelion,

or a fibrous root system, like certain bunch grasses; in either case there is a well-developed perennial crown. Under natural conditions these perennials propagate only by seed; but if the roots of such plants as the dandelion, or the crowns of the bunch grasses, are broken into pieces, each piece is capable of rejuvenating the plant.

The creeping perennials are the most difficult type to control because they reproduce by creeping underground stems (rootstocks or rhizomes) as well as by seed. Among the most common are Johnson grass, hoary cress, morning-glory (fig. 2), Canada thistle, and Russian knapweed. These not only spread horizontally for appreciable distances underground but have deeply penetrating roots. Morning-glory roots have been found over 20 feet deep in the soil.

Bulbous perennials reproduce by bulbs or nut-like structures and by seeds as well. Their reproductive organs are often but weakly attached to the mother plant and are easily dragged loose and scattered through the soil during plowing and cultivation. Some common bulbous perennials of California are wild onion, wild garlic, and nut grass.

METHODS OF CONTROLLING PERENNIAL WEEDS

In combating perennial weeds, two problems are involved. First, to check spread or reinfestation by seedlings the old plants must be prevented from ripening seed, and seedlings developing from seed already present in the soil must be killed. Second, the existing stand of old established plants must be eradicated.

In handling the seedling situation, one may use methods similar to those already described for annuals, except that the greater hazard involved makes it much more important to prevent the spread of seed. Mowing in the blossoming stages, spraying with contact sprays, or burning will accomplish this purpose. Probably early spraying or mowing, followed by spraying of the stubble after removal of top growth, is the best way to prevent seed formation. Plowing or shallow cultivation, if done early enough, will kill seedlings of perennials. Morning-glory seedlings may be controlled in the two to five-leaf stage by two cultivations to a depth of 3 inches on unirrigated land or four cultivations after each irrigation on irrigated land. If allowed to become more mature, the plants assume a perennial habit, and eradication becomes much more difficult.

In controlling or eradicating established perennial weeds, several methods are effective. Certain requirements limit the vigor of such plants and their ability to perpetuate themselves. All, for example, need sunlight, oxygen, water, and certain mineral nutrients from the soil. If any one of these factors is limited, either by cultivation, smothering, or immersion under water, or by competition with other plants, the vigor

of the plant is reduced; and if any one is rendered permanently unavailable, the plant must ultimately die.

In addition, the perennial plant goes through a more or less normal annual cycle of vegetation, reproduction, storage, and dormancy; and any disturbance of this cycle lowers its vigor. A plant may be induced, furthermore, under certain limited conditions, to take up a chemical through cut or injured tops; the poison is then translocated to the roots, killing all tissue with which it comes in contact. And finally a plant, under other conditions, may absorb toxic chemicals from the soil and die when these accumulate sufficiently. With these points in mind present methods for controlling perennial weeds will be discussed.

Clean Cultivation.—If a perennial plant is not allowed to send leaves up into the sunlight and air, food manufacture is prevented, and the roots are killed. This principle underlies the old practice of clean cultivation. Although excellent in some places, this method has drawbacks in California. On our deep alluvial soils the roots of such perennials as morning-glory are so extensive that two or more years are often required for depletion of food reserves. In unirrigated soils, as the soil moisture runs low the roots tend to become dormant; thus their food consumption is reduced, and their life prolonged. This difficulty may be overcome by occasional irrigation where possible. Any seeds formed on the infestation may later be brought to the surface and in certain crops, such as cereals, may reinfest the areas. In fact, cultivation tends to spread the seed so that if reinfestation occurs the areas are larger than ever. A clean cultivation program, once inaugurated, involves watching the areas closely for years after the old plants are gone. In California the actual areas of infestation should be kept free of crops during the first year of cultivation, because it is almost impossible to keep down growth around crop plants.

In dry-land areas, summer fallowing not only disturbs the roots to the depth of plowing but, if followed by a weed-cutting program, accomplishes the same result as clean cultivation when conscientiously carried out. Although pasturing of fallowed land tends to check such perennials as morning-glory, it does not appreciably reduce the stand.

Flooding.—A practice increasingly popular in California for controlling perennial weeds is flooding. This is accomplished by surrounding the areas with dikes and covering them with 6 to 10 inches of water for several weeks in the summer. The infested area should be plowed before immersing, and no growth should be allowed to appear above the water.

Flooding first attracted attention when areas infested with morning-glory and other noxious perennials were planted to rice. Such weeds

were usually eradicated. This method has been used rather extensively with camel thorn and hoary cress (fig. 3) and yields excellent results in sandy soils. In heavy soils flooding has not been so satisfactory.

White horse nettle occurring in several of the camel-thorn areas has been killed in nearly every instance. In Stanislaus County a 13-acre area of Russian knapweed, flooded for 60 days, was completely killed. In

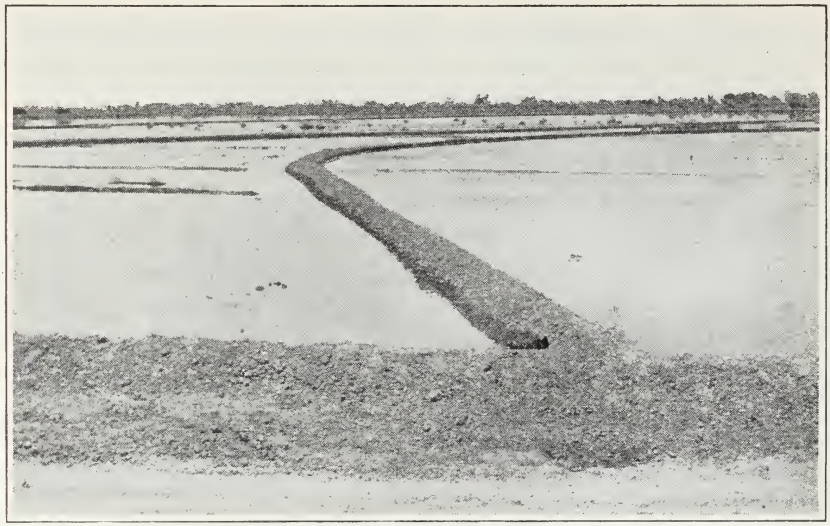

Fig. 3.—An area in Imperial County, infested with hoary cress, flooded to eradicate the weed.

several other places knapweed has given the same response. Occasionally submergence for three to five weeks has given satisfactory control.

As results of flooding have varied on different soils, soil type is evidently a factor. Flooding is effective only where the area is completely immersed for the whole time of treatment. Many failures have resulted from allowing the water level to lower so that regrowth occurred. Not all weeds react in the same way to flooding and our information is not yet complete enough to warrant general recommendations.

As flooding kills plants by excluding the air, it is effective only when the plant is covered and the roots completely surrounded with water. Under certain soil conditions some plants apparently become dormant and thus, through lowered oxygen consumption, are enabled to survive.

Cropping Methods.—In several cases recently noted in California, morning-glory, creeping mallow, and other perennial weeds have disappeared in certain crops. After the serious outbreak of curly top in the sugar-beet area of the Salinas Valley in 1925, lettuce culture was inaugurated; within three years the extent and vigor of morning-glory infestation markedly decreased. Two years ago the Agronomy Division at

the University Farm, Davis, found that morning-glory had almost disappeared in certain of their alfalfa plots. A series of alfalfa plots plowed in 1934 proved to be almost free of this pest, although the area had been heavily infested four years previously when it was planted. A grain-sorghum crop grown there during the summer of 1934 was practically free of weeds. Encouraged by these results the Agronomy Division, which had previously spent hundreds of dollars annually in spraying and hoeing morning-glory, has initiated a 5 to 6-year plan of crop rotation, with alfalfa serving the dual rôle of legume for soil improvement and competitor for weed control.

Studies now under way explain the effectiveness of alfalfa as a weed-control crop under California conditions. Though no definite report is yet possible, several factors are apparently involved in this response. In the first place, alfalfa grows vigorously and competes effectively with the weed for soil moisture and nutrients. Aboveground it shades the sun-loving morning-glory. Furthermore, it takes the available nitrates from the soil rapidly in the spring and then utilizes nitrogen fixed by the bacteria in its root nodules. Thus it can maintain a low nitrate level in the soil and yet thrive in competition with a nonlegume. By the second crop in the summer following spring planting of alfalfa at Davis, the morning-glory becomes spindling and light green, evidencing nitrogen deficiency. This condition progresses throughout the season and, although less apparent in the first crop of the following season, becomes very pronounced during the second summer. Meanwhile, if the alfalfa is vigorous, the stand of morning-glory becomes notably weaker and thinner. By the third season only a fraction of the original infestation remains and by the fourth it is practically gone. Finally, morning-glory likes to grow vigorously without competition in the spring, blossom, fruit, and mature seed during the summer; and then, with the depletion of soil moisture, die down and go into dormancy until the next spring. When this cycle is disturbed the plant suffers. In both lettuce and alfalfa culture, in addition to frequent cutting, which tends to keep the plant vegetative, the soil is kept moist, inducing continued growth. This long vegetative period reduces starch reserves in the roots to a minimum and then fails to provide for replenishment. The roots consequently start the winter in a depleted condition and fail to survive, especially if the rainy season is long and wet. Apparently, then, several factors operate in this cropping method; and when they favor the crop in comparison with the weed, excellent results are obtained. The benefits are threefold: not only are the weeds eliminated, but the soil is improved in fertility and physical condition, and a valuable crop is produced.

Besides alfalfa, ladino clover offers some promise as a control crop for

weeds. Although it does not provide so much shade nor such keen root competition, it may be grown on a wide variety of soils not suited for alfalfa. It may take longer, but it should eventually give the same results.

In addition to these two legumes, several combinations will be tested for their value in weed control. Most of them consist of an annual legume and a nonleguminous truck or field crop. Crop rotation has not been sufficiently stressed in this state, where large areas of the most fertile lands are still under a system of bonanza farming.

Smothering.—The control of perennials by smothering with straw, manure, or paper, though not practicable for large infestations, may be successful on small patches. Weeds with indeterminate growth, like morning-glory, are extremely difficult to keep under cover. On others more easily managed, like Bermuda and Johnson grass and Russian knapweed, smothering has proved successful. If continued long enough, it should be effective on any plant that can be successfully covered.

Smother crops are not so generally useful in California as elsewhere. Millet, Sudan grass, sweet clover, sunflowers, rape, rye, and sorghums, unless combined with some other agency, can do little except hold the weed in check. Any crop that offers competition, however, tends to reduce the vigor of perennial weeds and to check their spread; and it is always advisable, if nothing else can be done, to plant one of the crops just listed rather than let noxious weeds thrive undisturbed.

METHODS OF CHEMICAL WEED CONTROL

Within the past few years, progress has been made in chemical weed control. Not only have new chemicals been added to the list of herbicides, but research has increased our knowledge of the reagents previously used. Although no revolutionary methods have been introduced, recent information permits a much more intelligent application of chemicals than was possible in the past.

The types of herbicides being used with success in California are as follows:

Contact Herbicides.—These chemicals kill only the tissues to which they are applied. They include oils, dilute sulfuric acid, dilute sodium arsenite, 2 per cent sodium chlorate, iron sulfate, copper sulfate, and sodium metaborate. They are used principally on annual weeds to prevent seeding, to reduce fire hazard, and to destroy weeds which harbor insect pests and plant diseases.

Selective Sprays.—These solutions, applied to mixed vegetation, kill the broad-leaved annuals having exposed growing points but do not seriously affect cereals and grasses. Dilute sulfuric acid, iron, copper,

and ammonium sulfate solutions are the most important. Although Kainite and calcium cyanamide are used as dusts for the same purpose, the fertilizing elements that they carry are not usually required in California soils; they cannot, therefore, be generally recommended.

Translocated Sprays.—These sprays not only affect the tissues to which they are applied but, under certain rather specific conditions, are carried through the conducting system of the plant deep into the roots or rootstocks. For this purpose a solution containing ½ per cent arsenic trioxide in the form of sodium arsenite and 5 per cent sulfuric acid by weight has been found most satisfactory. Other chemicals that will have the same effect on plants are arsenic acid, arsenic trichloride, and sodium chlorate. Translocated sprays are used on certain deep-rooted perennials.

Temporary Soil Sterilants.—Sodium chlorate applied in the fall or early winter, either dry or in solution, will be leached into the soil by rains. After plant roots have absorbed a sufficient quantity of this compound, the entire root system may be killed. By decomposition and leaching, the chemical is gradually lost from the soil, so that in time crops may be grown. The success of a given treatment depends upon factors to be discussed later in detail.

Carbon disulfide injected into the soil and sealed in by a compact or moist soil layer will volatilize and fill the air spaces with a vapor poisonous to plant roots. It diffuses, usually in 3 to 6 weeks, leaving the soil unaffected for subsequent crops.

Relatively Permanent Soil Sterilants.—These chemicals, applied directly to the soil, render it sterile for several years. They act as poisons, killing the emerging seedlings. Among them sodium arsenite, arsenic trioxide, sodium chlorate, and various sodium borates are the most promising. They are used on ditchbanks, roadsides, fence lines, and other waste areas to prevent all plant growth.

As shown by the discussion of weed characteristics, there can be no universal method of controlling these pests. Methods must be adapted to the specific weeds and to the attendant conditions as these factors relate to the problem at hand. In any intelligent practice the properties of the weed and their relation to the environment largely determine the reagent to be used and the method of application. General recommendations, therefore, must be interpreted and amended. Their use should be tempered with judgment and, if possible, based upon local experience.

With these points in mind, the various methods for using herbicides in practical weed control will be discussed in detail.

SEASONAL CONTROL OF WEEDS IN UNCROPPED AREAS

Under this heading will be considered the contact sprays used principally on annual weeds, as contrasted with the more permanent method of soil sterilization. One should note at the outset that, wherever possible, mechanical means rather than chemical are more economical for controlling annual weeds. This matter will be further considered in a later section. On some areas, however, chemicals can be used economically; and there is then considerable question as to the most suitable reagent.

The principal agencies now engaged in seasonal control of weeds in California are the railroads and the State Highway Commission. Broadly speaking, their purpose is threefold: fire prevention, pest control, and elimination of unsightly weed growth. Many farmers and industrial organizations have followed their example and adopted their methods. Although these activities have served as a country-wide demonstration of the effectiveness and practicability of chemical weed control, improvements in method could probably be made at the present time.

Oils.—The Highway Commission has used Diesel oil almost exclusively in its control program. This material, being relatively cheap in California, can be applied at a cost of 5 to 6 cents per gallon. Application rates vary from 300 to 500 gallons or more per acre, according to the height and density of the vegetation. The oils have sometimes been used at the time of burning the dead vegetation. Oil that penetrates the seed coat almost invariably kills seeds.

The cost of such treatment is not prohibitive and, in view of the property saved, has been thoroughly justified. In some seasons, however, late spring rains stimulate a second crop of weeds on the sprayed areas and two or more applications become necessary. Diesel oil, furthermore, has little cumulative effect and must be used every year. For these reasons the method of chemical soil sterilization could perhaps well be applied to this problem of roadside weed control, at least in regions where climatic and soil factors would favor effective results.

Diesel oil is, at best, strictly a contact killer. It spreads very well on all vegetation and is particularly effective on grasses. It kills most rapidly during hot weather and, if properly applied, will destroy all vegetation down to the ground level.

For a comparison of oils and mechanical methods in the control of roadside weeds, see page 49.

Sulfuric Acid.—The increasing use of Diesel oil as fuel and the attendant rise in price make it advisable to consider a substitute. In this field dilute sulfuric acid seems to offer the greatest possibilities. It does not spread well, but certain commercial spreaders now available may

solve this problem. Improved equipment described in a later section also favors the use of this material. Experiments now in progress look toward the use of sulfuric acid both in aqueous solution and in an oil emulsion as a herbicide for annual weeds. No recommendations for other weeds than mustard and wild radish can yet be given; but possibly, as Diesel oil is required in greater amounts as a fuel, sulfuric acid will take its place in weed control.

Sodium Arsenite.—For years the railroads have used a dilute sodium arsenite solution as a weed killer on their roadbeds. This practice, though inexpensive and fairly effective, has led to numerous lawsuits over poisoned cattle and has impaired the popularity of chemical weed control. The continued use of arsenic in this way usually results in an accumulation; as a partial soil sterility is built up, the applications are required less often.

In view of the results recently obtained by using arsenic in heavier dosages as a soil sterilant, and the difficulties resulting from the present practice, the railroad companies would probably do well to apply the arsenic less frequently and in larger doses, making the application directly to the soil during the winter. Thus they would avoid many of the stock-poisoning cases; they would have clean roadbeds at all times; and they would be making more efficient use of the arsenic applied. The same could be said of all others who use dilute sodium arsenite as a contact spray. There seems to be little excuse for the continued use of arsenic solutions as "weed killers" on growing vegetation in view of our present knowledge of mechanical weed control and chemical soil sterilization.

CONTROL OF ANNUAL WEEDS IN CEREALS WITH DILUTE SULFURIC ACID[9]

The differential killing of broad-leaved plants in grain by chemical sprays has been known since 1896. Though experimental work with iron sulfate in the early years of this century indicated the possibilities of the method, not until investigations in Europe with dilute sulfuric acid proved the feasibility of the method did it become common. According to reports, 70,000 tons of sulfuric acid were used in weed control in France in 1933, and over 20,000 acres of cereal crops were sprayed in England in 1934. Much of this work, however, was done with knapsack or horse-drawn equipment on the small farms of those countries.

The large grain farms of California require boom equipment capable

[9] This section was prepared by Mr. W. E. Ball, Associate in the Experiment Station and Investigator for the Crop Protection Institute. The equipment used is more fully described in California Exp. Sta. Bul. No. 596, The control of weeds with sulfuric acid, by W. E. Ball and O. C. French.

of covering many acres per day. Coöperative work aiming toward development of such equipment has been carried on by the divisions of Botany and Agricultural Engineering at Davis during the last two years. A

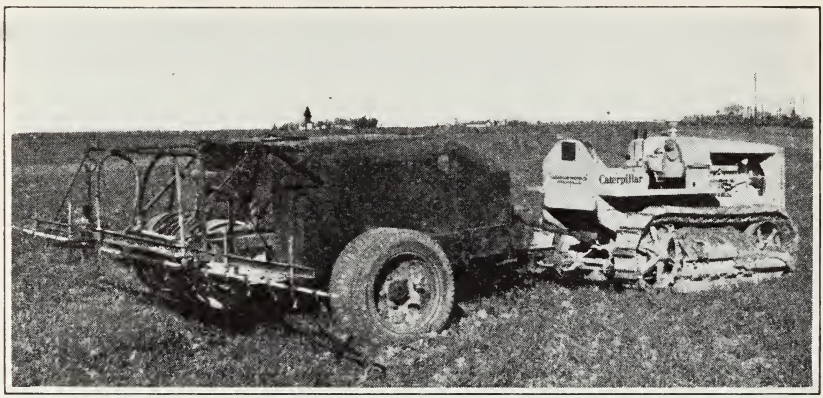

Fig. 4.—Equipment used in applying dilute sulfuric acid in the control of mustard in grain fields. The water tank has a capacity of 400 gallons; the drum containing concentrated sulfuric acid is attached behind the tank; the boom has a spread of 20 feet.

Fig. 5.—Mustard plants in the best stages of development for treatment with sulfuric acid. The corresponding sizes of grain plants are shown at the right. (From Bul. 596.)

machine (fig. 4) designed during the past winter, was used in the field throughout February, March, and April, 1935. At present this equipment appears satisfactory in the use of dilute sulfuric acid in California. It departs in design from the customary practice of pumping the herbicide directly. In it, water from the pump under a pressure of about 200 pounds per square inch is passed through a Penberthy ejector, which causes concentrated sulfuric acid to be drawn in directly from a container and mixed thoroughly at a fixed concentration. The amount of acid drawn into the water stream is controlled by an orifice in a thin

nickel washer held by a union in the suction line. The diluted acid from the ejector is distributed through a brass boom equipped with special nozzles. The nozzles on the boom are so arranged that the plants are sprayed twice from different angles as the boom passes over them, giving a very satisfactory coverage. All parts of the equipment coming in contact with the acid are of brass, and little corrosion could be found after the first

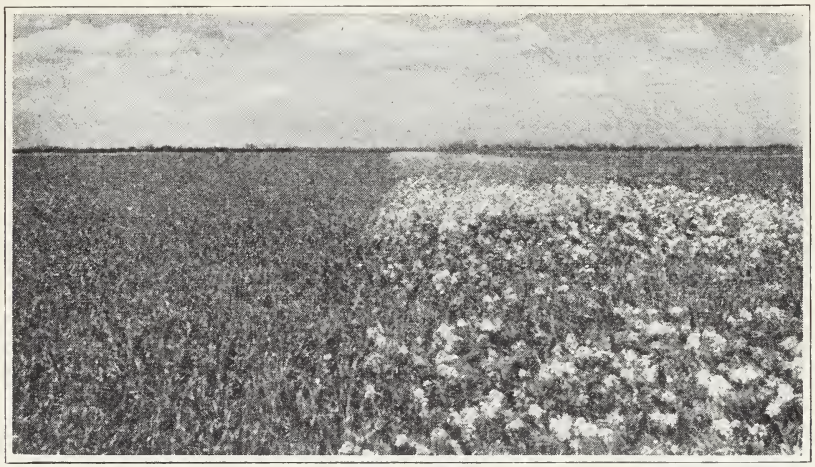

Fig. 6.—The effect of dilute sulfuric acid in the control of wild radish in wheat. The unsprayed strip at the right is indicated by the radish in bloom. (From Bul. 596.)

season's run. Many standard orchard sprayers may be readily converted at little cost into equipment of this nature.

With this method best results are obtained by spraying mustard from 4 to 7 inches high (fig. 5). Control approximating 90 to 95 per cent has followed such treatments. A solution of 10 per cent sulfuric acid by weight at a rate of 130 gallons per acre has proved best. The concentration of the acid discharged may be measured with a hydrometer, which gives the specific gravity of the solution. A 10 per cent solution by weight at 25° C has a specific gravity of 1.064. Concentrated sulfuric acid weighs approximately 15 pounds per gallon. A pressure of 75 pounds per square inch at the nozzles gives excellent coverage. Additional pressure causes undesirable drifting of the spray.

At present prices the acid costs about $1.40 per acre. Cost of application depends largely upon the size and efficiency of the spraying operations. With the equipment mentioned above, operating at $1.50 per acre, the total cost was approximately $3.00 per acre.

This method, though used principally to control mustard, is also effective against wild radish, *Amsinckia,* various *Chenopodium* and *Atriplex* species, thistles, clovers, and other annuals occurring in grain.

In the experimental work, control of some of these other species has brought greater increases in yield than when only mustards were killed. Another unforeseen virtue of the sulfuric acid spray is that the treated grain is less subject to lodging; thus the harvest yield may be further increased. In heavily infested fields the treated areas have yielded 50 to 60 per cent more grain than the untreated (fig. 6).

In mixing acid and water, always add the acid to the water, not the water to the acid. Wear old clothing, for the acid is corrosive; and choose rubber or woolen clothes rather than cotton. A solution of bicarbonate of soda will neutralize any acid splashed on the hands or face.

To summarize, dilute sulfuric acid has many advantages as a weed-control agent: (1) it is economical, a gallon of 10 per cent solution costing approximately one cent; (2) it is neither poisonous to livestock nor combustible; (3) it reacts with plant tissue very quickly and is therefore not seriously affected by climatic conditions; and (4) it is not detrimental to the soil as are certain common weed sprays.

Dilute sulfuric acid has one unfortunate characteristic: it is highly corrosive to most metals and to clothing. This difficulty has been largely overcome, however, by the special equipment described above.

THE ACID ARSENICAL METHOD

The control of deep-rooted perennial weeds requires a herbicide that will kill the roots and rootstocks of plants as well as the tops. An acid arsenical solution developed at Davis will do this with fair success on certain of our noxious weeds. This type of spray depends for its effect upon translocation; the chemical moves within the plant from the tops to which it is applied, deep into the underground organs. This movement of the herbicide within the plant depends in turn upon a physiological response to the spray. For this response to occur, certain conditions are required; in fact, they largely determine the results of a given treatment.

The mechanism responsible for the movement of the arsenical herbicide into the roots after its application to the leaves is as follows: During the summer days in California loss of water from the leaves usually exceeds uptake by the roots. When this happens, pressure within the water-conducting tissues of the plant becomes reduced or subatmospheric, and water is drawn from turgid living cells throughout the plant. When this process takes place very quickly the plant promptly wilts; but when the condition develops slowly, the plant may adapt itself somewhat and a large water deficit may exist with little visible evidence.

When a plant with a large water deficit in its tissues is sprayed with a strongly acid solution, the living cells of the leaves and stems are

rapidly killed and rendered permeable, and all moisture free to move is forced into the water-conducting tissue and carried down into the roots. If the spray solution contains arsenic, this poison will diffuse into the killed tissue and, mixing with the sap, will also be drawn into the roots. The depth of its penetration and the thoroughness of its distribution into the root system depend upon several factors. Among these water deficiency in the plant tissues has been mentioned. In addition, the water-supplying power of the soil must be low, or the deficit will be satisfied with water absorbed by the roots. The plants furthermore must have a large top growth to allow application of sufficient arsenic; spraying must be done at night so that the chemical can act before the solution dries on the leaves; and the effectiveness can be further enhanced by making the total application in two separate sprayings, followed next morning with one or more applications of water.

To summarize: the acid arsenical spray should be applied after dark in the summer or fall to mature plants having ample top growth, which have been allowed to grow undisturbed until the available soil moisture is practically depleted. Spraying should not be done during unusually hot, dry, or windy weather.

Success largely depends upon the type of growth of the plants. With morning-glory in central California the best results are probably obtained by allowing the first flush of growth in the spring to mature and then spraying in June or early July. If this plan cannot be followed, the areas may be irrigated at any time during the summer before August 15 and then allowed to mature and to deplete the soil moisture before being sprayed. The best index to the soil moisture supply is the condition of the plants; lush, green foliage with rapid end growth on all shoots denotes high moisture. When moisture becomes limiting, end growth ceases, and the foliage tends to reach an even state of maturity. Only when this condition is reached should the spraying be done.

Where morning-glory has been cultivated several times during the summer and later allowed to mature, the results with the acid arsenical have been less satisfactory. Only when an irrigation is used to insure a uniform, abundant growth of foliage is this plan successful. Where irrigation is not available, the early summer growth should be normal to insure satisfactory treatment. During the winters of 1932–33 and 1933–34, the rainfall was deficient at Davis, and the spring growth of morning-glory was sparse. The soil had been moistened to less than 3 feet, and the roots of plants treated with the acid arsenical during the subsequent summers were only superficially killed. This method, therefore, is inadvisable on morning-glory in seasons when the rainfall has been notably deficient unless irrigation water is available to produce a heavy growth.

The average stand of morning-glory can be covered with about 250 gallons of spray per acre. For satisfactory results about twice this amount is required. To conserve the solution and provide maximum

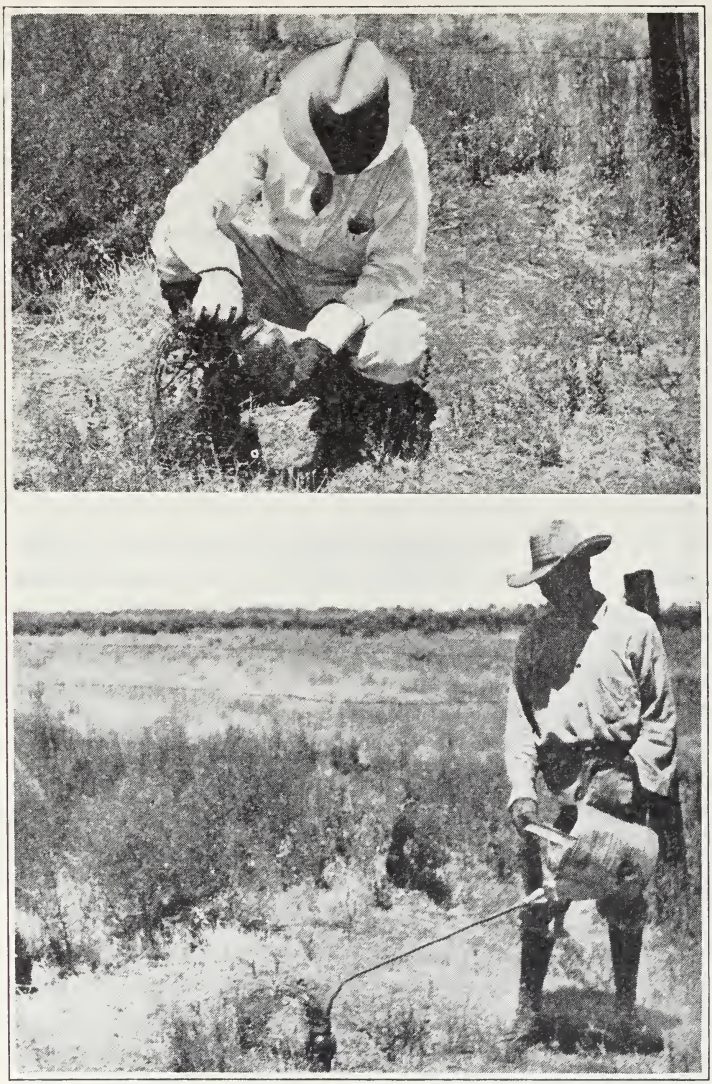

Fig. 7.—Showing use of the "jar method" in treatment of camel thorn. Upper, inserting the top of the plant in the jar; lower, filling the jar with a 1 per cent arsenic solution. The plants are left in the solution for 24 to 48 hours.

penetration, the areas should be sprayed at a rate of 250 gallons per acre and then, after an interval of 20 to 40 minutes, sprayed a second time. This insures maximum coverage and gives the first application time to

act on the foliage so that the second penetrates rapidly. Where the foliage is very heavy the treatment can well be increased to two applications of 350 gallons per acre, or three of 250 gallons. Proper spraying equipment will be described later.

The results thus far obtained with the acid arsenical have been best on Russian knapweed, variable on morning-glory, even less successful on alkali mallow, and negligible on hoary cress. Success is probably related to the root structure; plants having abundant storage tissue as compared with the woody water-conducting cylinder give the most satisfactory response.

A modification of the acid arsenical method has been useful on some perennials. In this "jar" or "dipping" method, as it is called, the sulfuric acid may be omitted, although there are some indications that its presence is not detrimental; the tops of the plants are simply bent over, forced into a glass jar or tin can (fig. 7), and covered with a solution containing 1 per cent arsenic trioxide by weight. To make a 1 per cent arsenic solution, add 2 pounds of the stock solution described on page 31 to 100 pounds of water. As the foliage is killed and rendered permeable by the arsenic, the solution is drawn into the root system until all water deficiency is satisfied. Even better results are obtained on weeds that are interconnected through their roots. In this case, if one plant is treated all the connected plants draw on the solution and the entire system is killed. This situation occurs in camel thorn, where excellent results have been obtained. The method is also useful in killing individual morning-glory plants in gardens or strawberry beds. Although effective on camel thorn, morning-glory, and white horse nettle, it gives less favorable results on Russian knapweed, hoary cress, or alkali mallow. This method is usually practicable only in scattered infestations of perennial weeds.

Other chemicals used as translocated sprays are arsenic acid, arsenic trichloride, and sodium chlorate. The first two are no more effective than arsenic trioxide used according to directions to be given, and they are more expensive. Although sodium chlorate is nonpoisonous to livestock, as a translocated spray it has all the limitations of the acid arsenical, besides being much more expensive. If followed by an application of 5 per cent sulfuric acid, the chlorate spray is effective at a dosage of 1 pound per square rod on morning-glory. In this form the method might find some use in pastures. Under most conditions, however, this chemical gives best results when used in a soil treatment.

Preparation of the Acid Arsenical Stock Solution.—The spray solution used in the acid arsenical method is easily prepared and applied. It consists of a stock arsenic solution, concentrated sulfuric acid, and water.

The stock solution is composed of 4 parts by weight of arsenic trioxide, 1 part of sodium hydroxide, and 3 parts of water. When mixed in these proportions the chemicals react, evolving heat, and dissolve rapidly.

Enough stock solution for one-half acre or more can be conveniently mixed in a bucket or can of about 5 gallons' capacity. For this small amount mix thoroughly, in the dry condition, 20 pounds of arsenic trioxide (As_2O_3, white arsenic, arsenious oxide) and 5 pounds of sodium hydroxide (NaOH, caustic soda, soda lye) in the bucket. Weigh out 15 pounds of water and add about half of it to the mixed chemicals, stirring to loosen the arsenic and lye. The mixture will heat rapidly; as it approaches the boiling point, the arsenic goes into solution, forming sodium arsenite. If boiling becomes violent, add a little cold water. Continue to stir, loosening the chemicals from the bottom until they are entirely free in the solution. When boiling ceases, any arsenic that remains undissolved should be mashed against the container with a paddle. A piece of wire screen can be used to hold the lumps of arsenic against the side while mashing. When the chemicals are completely dissolved, add the remaining weighed water, stir thoroughly, and strain through doubled cheesecloth. This stock solution is now ready to use. It can be kept a few weeks but will crystallize if allowed to evaporate. It can be redissolved by boiling.

Preparation of Large Quantities of Stock Solution.—Equipment for mixing 160 pounds of stock solution at a time can be made by mounting a 50-gallon oil drum horizontally upon wooden rockers. A large opening in the center on top and a gate valve or molasses spigot in one end at the bottom allow for adding the chemicals and withdrawing the solution. There should be a cover for the top opening. To prepare a batch, weigh out 60 pounds of water, pour 30 pounds into the drum, and add 20 pounds of sodium hydroxide. Mix by rocking the drum so that the solution splashes violently against the ends. Weigh out 80 pounds of arsenic trioxide; as the solution warms, add it a few pounds at a time, using a sugar scoop or can. Mix well between additions. If boiling becomes violent, add more water. Keep the opening covered between times. When the arsenic is all in solution, add the remaining water, mix well, and draw off through a fine screen or cheesecloth filter. By using a 100-gallon drum, one can prepare even larger quantities and save considerable time. This stock solution contains 50 per cent As_2O_3 by weight and weighs approximately 16 pounds to the gallon.

The Spray Solution.—Experiments have shown that a satisfactory spray solution must contain at least ½ per cent arsenic trioxide by weight and 5 per cent sulfuric acid. To make 3 gallons of this solution, for a knapsack sprayer, add to 3 gallons of water ¼ pound of stock

arsenic solution, stir well, pour in 1¼ pounds of concentrated sulfuric acid, mix, and apply. For a 100-gallon lot pour 8 pounds (approximately ½ gallon) of the stock arsenic solution into 96 gallons of water in the spray tank, agitate thoroughly, add slowly 40 pounds (approximately 2½ gallons) of concentrated sulfuric acid, agitating constantly. Best results follow application of at least 500 gallons per acre of solid infestation, using 75 to 100 pounds' pressure with Chipman nozzles. When the temperature is low, more acid may be used to increase the rate of penetration. A boom outfit with fixed nozzles gives more complete coverage than hand application. Some advantage may be gained by dividing the total treatment into two separate applications of 250 to 300 gallons each with an interval of 20 to 40 minutes between them. If there is considerable wind or the foliage is unusually dense, at least three such applications should be made.

Precautions.—Use extreme caution in mixing and applying these solutions. Do all mixing in the open air, avoiding fumes. The stock solution heats rapidly and spatters. Keep to one side if mixing it in an open container. The boiling solution, being extremely hot, will cause severe burns and poisoning. *Soluble arsenic is extremely poisonous.* Keep stock and spray solutions out of cuts or open sores; avoid all contact as much as possible. In making up the spray solution, *pour the acid into the water* with constant stirring. Avoid slopping and spilling. Sulfuric acid will cause severe burns and will rapidly dissolve cotton clothing. Even the 5 per cent acid of the spray solution will ruin clothing. Keep a bucket of bicarbonate of soda (baking soda) solution available on the spray rig and immediately wash hands, face, or clothes that come in contact with the spray.

Arsenic is poisonous to livestock. One week after application of the spray the weeds may be burned, disked, or plowed under. If they are burned, avoid the smoke, as it carries arsenic and may cause serious poisoning.

TEMPORARY SOIL TREATMENTS

Sodium Chlorate.—Sodium chlorate, a white crystalline substance, is obtainable from any large chemical supply house, usually in a finely divided form not unlike table salt. Though relatively nonpoisonous, it involves a fire hazard, which will be discussed later. The proprietary herbicide "Atlacide" is a mixture of sodium chlorate and calcium chloride.

Workers on weed control have been much confused as to the way in which sodium chlorate kills plants. It is becoming apparent, however, that the principal action, under most conditions, is through the soil.

As described above, the plants absorb this chemical; and, when enough has been accumulated, they sicken and die. Recent work in California has determined the main factors involved in the successful use of chlorate through the soil.

Before going into the more specific effects of chlorate, we may consider briefly the inherent differences in plants with respect to injury. Many plants are easily killed. When sprayed with a contact herbicide or cut off at the ground level, they die. Others will resprout from the stump or crown; and still others, including many noxious weeds, will regenerate from underground stem or root tissue and are eradicated only when all vestiges of these tissues are killed. In treating a variety of plants with sodium chlorate, one is sure to find differences in the degree of control; and unless he has previously determined the response to mechanical injury, he cannot interpret accurately his results. Plants differ widely, furthermore, in their susceptibility to injury by chlorates. In one instance reported, a certain parasitic plant was controlled by the use of 12 pounds of sodium chlorate per acre. In other cases, over 1,000 pounds per acre have failed to control certain resistant species. This problem of species' susceptibility must be considered in prescribing the dosage for any particular situation.

The influence of soil type upon chlorate toxicity is another important factor. Although experiments are still in progress and final determinations have not been made, it now seems that, within a soil series, toxicity of chlorate runs higher in the coarser textural grades. Among series, alluvial soils of recent origin show the lowest toxicities; old weathered soils the highest. A recent survey of several California soils shows one exception to the first rule. Extremely heavy clays and adobe clays show high toxicities. This is very apparent in primary clay soils and in heavily leached or water-laid clays. Soils high in organic matter, such as peats or semipeats from the Sacramento River basin, show low toxicities comparable with those of the highly fertile recent alluvial soils.

Another factor in the use of chlorate through soils is that certain soils retain this chemical so that it does not move freely with soil moisture. In general, soils showing the lowest toxicity have the strongest ability to retain chlorate, and in them the vertical distribution of applied chlorate is a problem. In Davis, morning-glory must be killed to a depth of at least 4 feet or it will resprout and survive. In a Yolo loam soil, chlorate has been leached to that depth with 6 surface inches of water. In a Yolo clay, double this amount was required. Where the moisture comes as rainfall with opportunity for evaporation between storms, even more water would be needed. This one factor probably explains many of the failures with chlorate treatments in the arid regions of the West.

Chlorate decomposition is conditioned largely by moisture and temperature. In the humid sections where soils are moist during the summer, little difficulty is experienced with residual chlorate. In the West, where the soil is dry during the summer heat, sterilization has sometimes persisted for three years or longer. As experiments have shown, leaching with water is the easiest way to rid the land of chlorate. Where irrigation water is not available, chlorates must be used with considerable discretion on heavy soils.

The proper season for chlorate application has been frequently discussed, and the issue has been confused by results of applications made in the West according to recommendations formulated in the humid East. In California, experiments indicate three feasible methods: (1) fall spraying where rapid absorption and root killing, after translocation of part of the chlorate, are followed by leaching by the winter rains and absorption from the soil; (2) a straight soil treatment during the winter; (3) spring soil treatment followed by proper irrigation. All three methods aim to provide a lethal concentration of chlorate in the soil solution during the spring for absorption by the roots during the period when they are depleted of organic foods and engaged in rapid absorption from the soil. The methods are subject, however, to differences in growth conditions and soil type; and the first two, which depend upon rainfall, must be used with utmost care.

Evidently, then, there can be no universally successful procedure with chlorates. Because of the extreme variations in species' susceptibility and the numerous factors affecting toxicity and absorption, methods must be adapted to conditions.

In so complex a situation, recommendation of dosages is hazardous. The old formula of 3 pounds per square rod applied in 3 gallons of water is a good average figure. For morning-glory at Davis it represents a bare minimum; 4 pounds would be a better general dosage. For hoary cress in a Yolo type soil 6 and even 8 pounds were not enough. In the same locality 4 pounds were satisfactory on a Montezuma adobe clay. Whereas 2 pounds per square rod killed Bermuda grass in Fresno sandy loam at Turlock, 8 pounds were not enough in Yolo clay at Davis. As these few figures show, experimentation by trial-and-error under local conditions is the only reliable method for determining dosages. In this case a little local experience is worth much more than a large amount of expert advice.

In the soil-treatment method, concentration of the applied solution has little significance and becomes mainly a matter of convenience. In the first method listed above, where translocation plays a part, the concentration should be equivalent to one or more pounds of sodium chlorate

per gallon of water to insure prompt penetration. For the straight soil treatments the chemical may be applied dry provided uniform distribution can be had.

Precautions.—Many warnings have been sounded as to the dangers of sodium chlorate. Though the soil-treatment method tends to minimize the hazard, one should remember the properties of this chemical and be cautious. Sodium chlorate added to organic material, such as cotton cloth, wood, or straw, forms a mixture similar to black gunpowder, being *highly inflammable and easily ignited.* It burns with great violence and cannot be smothered, since the chlorate supplies the oxygen. The safest policy is to handle it with care and avoid spilling or loss from the containers. In case of fire, use water and flood the burning material.

Men should preferably not work alone in using chlorates. If two or more are together, assistance is at hand in case of fire. A bucket of water may extinguish the blaze and prevent a serious accident. Spray equipment should carry a fire extinguisher.

In handling chlorates, as during loading and unloading, or in preparing the spray solution, any crystals or solution accidentally spilled on floors, trucks, or machinery should be washed off with a hose or otherwise drenched with water.

As chlorates are particularly combustible when in contact with sulfur, great caution should be taken not to store sulfur, or spray materials containing sulfur, near chlorates. Moreover, a spray machine once employed in applying sulfur spray should be thoroughly washed inside and outside before being used for chlorates.

Accidents can occur after spraying operations are completed, if the clothing is allowed to dry on the body. This danger can be eliminated by having two pairs of overalls. At noon one pair can be rinsed out in clean water to remove all chlorate, and the dry pair put on for the afternoon; this pair, in turn, should be washed in the evening. Chlorate should not be allowed to dry on the operator's rubber boots, and they should be washed every evening.

Keep spray equipment well painted so that the solution does not saturate the wood. Metals are better than wooden containers for the chlorate solution. Wooden containers, if employed, should be washed out thoroughly after use and even allowed to stand for several days filled with water. A wooden barrel, for example, used for chlorate solution, when emptied and dried out, becomes highly combustible. As an extra precaution, mix solutions away from outbuildings, barns, or straw stacks.

Chlorates should be purchased preferably in metal containers. If shipped and stored in sacks they should be kept dry, for they absorb

moisture from the atmosphere; and the chemical, in close contact with the fiber of the sack, presents, when dry, a fire hazard.

In emphasizing these precautions, one should remember that chlorate sprays are no more dangerous than gasoline and other chemicals used

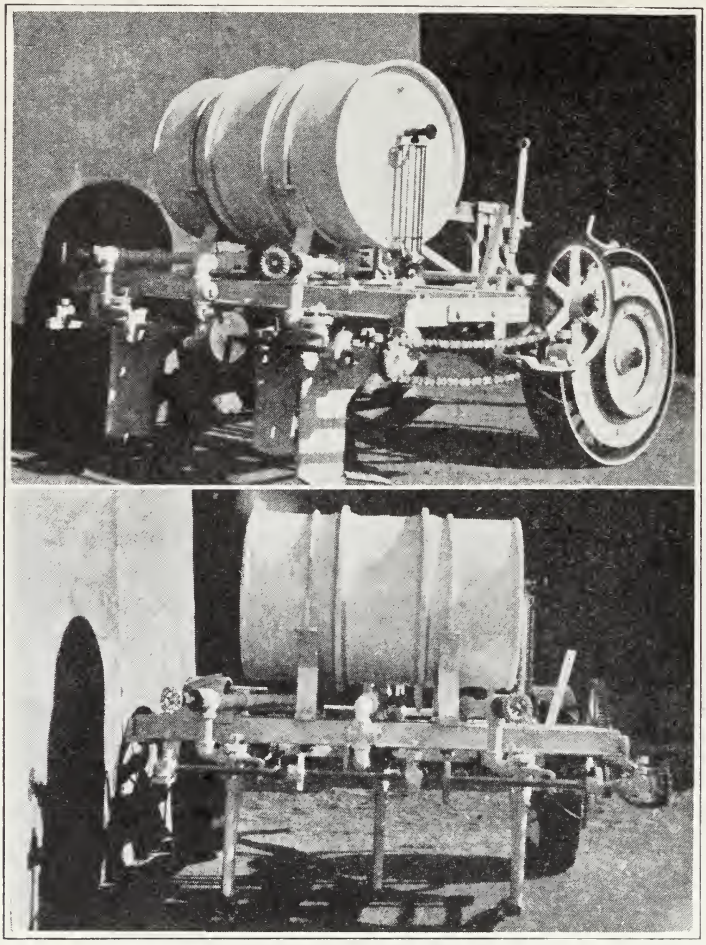

Fig. 8.—Mechanical applicator for carbon disulfide. Along the shank of each subsoiler is a tube carrying the chemical. Drum capacity, 550 pounds of carbon disulfide.

daily on the farm as insecticides and fungicides, and less hazardous than many chemical compounds handled constantly in the industries. If chlorates are effective herbicides, the care necessary should not be a serious drawback to their use.

Carbon Disulfide.—Another chemical that can be used as a temporary soil sterilant is carbon disulfide. A clear, volatile liquid, it readily vaporizes to give an extremely toxic gas, which is heavier than air. When

injected into the soil and sealed in to prevent excessive loss, it kills all roots within the treated soil mass and is therefore extremely effective in eradicating noxious perennial weeds.

Experimental work has been done which seems to show that the effectiveness of carbon disulfide is influenced by soil factors. The recommendations as to rates of application are sufficiently high to cover any small variations in toxicity and species' susceptibility and can usually be followed with reasonable assurance.

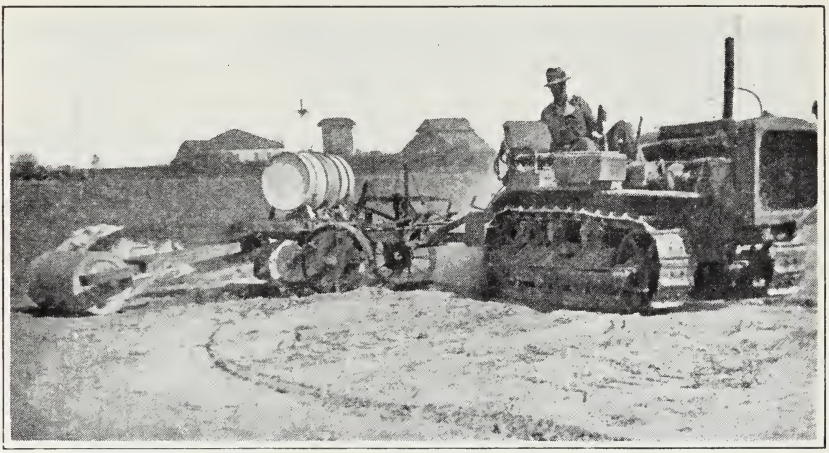

Fig. 9.—Equipment used in applying carbon disulfide. The mechanical applicator is followed by a heavy roller which compacts the soil, which prevents the ready escape of carbon disulfide fumes.

The usual method of treating small areas is to go over them with a weed cutter or hoe and then apply the liquid by making holes in the soil 18 inches apart each way in staggered rows and pouring from 2 to 4 ounces into each hole. The depth of application is important. If there is ample moisture in the surface soil the chemical should be applied at a depth of not over 6 inches, and then the soil thoroughly sealed. If, on account of lack of surface soil moisture, it is necessary to apply deeper, crown growth may occur because the fumes, being heavier than air, do not come into contact with the crowns in sufficient amount to effect a kill. As soon as the chemical is applied, the holes should be filled with soil and carefully tamped.

The manufacturers of carbon disulfide have a mechanical applicator (fig. 8) consisting of a 3-standard subsoiler equipped with a container, valves, and fittings. This machine, drawn by a caterpillar tractor, will apply a drum of the chemical in 20 minutes—under average conditions, a rate of one acre per hour.

In the treatment of large areas, care should be exercised in the prep-

aration of the soil prior to the application of the chemical. This usually means a shallow disking or plowing which will make possible a good sealing of the soil by rolling (fig. 9) after the chemical is applied.

The principal drawback to carbon disulfide is the expense. Treatments using equipment described above will cost from $200 to $250 per acre, according to the dosage and the method of application. The chemical has the advantage of leaving the soil rapidly so that crops may be grown; and being applied through the soil, it offers a higher degree of control than a translocated spray.

Carbon disulfide vapor is inflammable and, when mixed with air, is explosive. The liquid must be handled with care. Empty drums are particularly dangerous.

On small areas of shallow-rooted perennials, such as Bermuda grass and nut grass, carbon disulfide has been successfully used by sprinkling it on the surface of the soil and quickly covering it with damp canvas. The covering should be kept wet so that the vapor will not escape, and it must be left on for at least 24 hours.

SOIL STERILIZATION

With the intensification of agriculture on the more fertile soils of the state, pest control is increasing in importance. Considering the relation of weeds to insects and plant diseases, and the steady, persistent ingress of noxious species, complete control of all weed growth over waste areas in our more important agricultural districts appears highly desirable. In many areas, furthermore, weeds are now being controlled by inefficient methods with contact sprays and hoe labor. In these cases soil sterilization of all areas that cannot be handled by mechanical means seems highly advisable. For this work sodium arsenite has proved most effective, though arsenic trioxide, sodium chlorate, and certain borate ores offer promise.

Sodium Arsenite as a Soil Sterilant.—In the use of sodium arsenite in soils, toxicity is again affected by the type of soil. The chemical is most toxic in light, sandy soils and least in heavy clays. The adobe clays show high toxicities, which, however, decrease rapidly with time. In field-plot tests, 2 pounds of arsenic trioxide per square rod, applied in the form of sodium arsenite, has proved as effective on Fresno sandy loam as 8 pounds on Yolo clay. Over a fairly wide range of soil types, 4 pounds per square rod is usually recommended and gives excellent results. In the fertile recent alluvial soils and organic soils found in California, at least 8 pounds per square rod is required; and even this amount is soon rendered unavailable to plants.

The retention of arsenic in an available form in high concentration is

a common property of all soils studied. The concentration held depends upon soil type, being highest in the heavier soils; it also depends upon the dosage, being higher where applications are heavy.

Fig. 10.—Soil sterilization on a cement-lined ditch. Three-foot strips on each side of the ditch have been treated with sodium arsenite.

Arsenic in the soil is fairly resistant to leaching. Passage of 64 surface inches of water through 3-foot columns of soils failed to remove all the arsenic from medium and heavy-textured soils, whereas 16 inches removed it from Fresno sandy loam. In the field, arsenic applied at a rate of 4 pounds per square rod to Bermuda grass has been effective on the

Fresno soil but not on Yolo loam. Tests on the soil showed arsenic to be present in the sandy soil to a depth of 12 inches or more after the first winter rains. In the Yolo soil it was confined to the top 4 inches.

In field plots, 4 pounds of arsenic per square rod on Fresno sandy loam rendered the soil sterile for four years (fig. 10). Although enough rain fell during this time to leach the arsenic from the top soil, had it been applied continuously, the fact that it fell intermittently made it less effective in moving the chemical. This factor must be considered in interpreting the effects of rainfall on sterilized soils. Light, intermittent rainfall will not wash away the sterilant nearly so effectively as steady rains or flooding. For this reason, dosage and type of application of sodium arsenite for soil sterilization must be adapted to climatic conditions as well as to soil types. Where rainfall is heavy, excessive loss from leaching may be avoided by light annual applications. In drier localities, one heavy application may be effective for as many as four successive years.

Although sodium arsenite may be purchased in a stock solution known as "weed killer," if more than a few pounds will be required it may be economically prepared by the formula for the stock arsenic solution given on page 31. With the steel-drum equipment and with proper loading and emptying facilities, one man can make up to 4 tons of stock solution per day. This stock solution containing 50 per cent arsenic trioxide by weight may be diluted with water to any convenient volume for application. For the usual application of 4 pounds per square rod, a satisfactory solution is made by measuring out 8 pounds of the stock solution and diluting it with water up to a total volume of 3 gallons. Since the stock arsenic solution weighs approximately 16 pounds to the gallon, this would be, on a volume basis, a half-gallon of stock solution to 2½ gallons of water, making a 1:5 mixture. Though this dilution is recommended for general work, the proportions of stock solution to water may be varied between wide limits for any particular equipment or conditions. The important factor is the dosage in terms of arsenic trioxide in pounds per square rod. This is determined by soil type and environmental factors and should not fluctuate for any other reason.

Dry White Arsenic as a Soil Sterilant.—Arsenic trioxide or white arsenic, as it is commonly called, is much less soluble than sodium arsenite. For this reason it does not sterilize the soil during the first year after its application. By the second year, however, enough becomes available in the soil to affect plants; and from that time on its seems equal in effectiveness to sodium arsenite applied in solution. In fact, because of its low solubility, it seems more lasting than the arsenite and therefore more economical.

There are two possible ways of using this dry white arsenic in soil sterilization. It may be applied directly to the soil, with enough sodium chlorate added to give sterilization during the first year. This plan is particularly useful with perennials, for the chlorate will destroy many of the deeper-rooted weeds and the arsenic will be set free and kill annuals thereafter. Another method is to apply part of the total dosage of arsenic in the solution form and then to follow this with the remainder in the form of the dry white arsenic. The dry treatment is also recommended to follow a sterilization with sodium arsenite solution that is beginning to fail. It should be more permanent and economical than a second solution treatment.

The extremely poisonous nature of arsenic has been pointed out. In the large quantities used in soil sterilization it is particularly hazardous. To avoid killing livestock it should be applied to the bare soil in the early winter, after the first rains but before green vegetation has made any appreciable growth. *All treated areas should be posted with poison notices, and livestock kept away until 2 or more inches of rain have fallen. Special care should be taken to avoid applying arsenic to vegetation, either alive or dead, which may retain the poison and increase the hazard.*

The following precautions, prepared by a pharmacologist, should be heeded by all who use this chemical:

Avoid all contact of arsenic with the skin, for repeated contacts may cause a rash. Where unavoidable contact with arsenical sprays may occur, protect exposed skin, eyelids, and lips with white petroleum (vaseline).

Arsenical solutions are highly poisonous when absorbed into the body. Symptoms are nausea, vomiting, diarrhea, intestinal pain, scanty burning urine. In case of accidental swallowing of arsenic, take eggs, milk, and flour by mouth, and cause vomiting. *Call a doctor immediately.*

The accidental repeated ingestion of small amounts of arsenic over a long period may cause the slow appearance of symptoms of chronic poisoning, which are muscular weakness, scanty burning urination, and intestinal disturbance. If these symptoms are suspected, consult a doctor.

Nonpoisonous Soil Sterilants.—While arsenic may be used on ditch banks and other waste areas on privately owned land with relative safety, there are many places, such as public roads and schoolgrounds, where nonpoisonous chemicals are required. The permanence of a sodium chlorate treatment depends largely upon soil type and rainfall. In heavy clay soils and in regions of light rainfall, chlorate will sterilize the soil for two or more years. In other localities it still may be used by making annual applications in the late winter before vegetative growth becomes excessive.

Borax and certain borate ores not only have a lower solubility than sodium chlorate, but are retained in the soil in an available form against the leaching effects of moving water. This retention, though not so pronounced as with arsenic, makes the borates more persistent than chlorate. The toxicity of boron compounds in soils has long been known. Pound for pound, anhydrous borax is approximately as toxic as sodium chlorate or sodium arsenite. Its one drawback is a tendency to be fixed in the soil in an unavailable form rather rapidly. On the other hand, crude borate ores are much less expensive than chlorate or arsenic.

Borates are subject to the same wide variations of toxicity with soil type and species' susceptibility as are chlorate and arsenic. Used by themselves, they lack the intense killing power of these other chemicals. Combined with sodium chlorate they usually form very satisfactory sterilants.

According to experiments, a mixture containing 1 pound of sodium chlorate to 8 pounds of borax, Colemanite, or Kramer ore forms the best combination for soil sterilization. Applied dry at rates of 4 to 16 pounds per square rod, according to soil type and vegetation, it gives excellent results. One should not expect a single heavy application to last for several years; annual treatments with minimum effective dosages are more economical. Using this mixture dry during the winter on the bare soil reduces to a minimum the hazard of the sodium chlorate involved. One should, however, observe the precautions listed on page 35.

Although not on the market at present, Colemanite and Kramer ore are in production and could be supplied if the demand existed. Judging from tests, Colemanite is the most effective of the three boron compounds used, probably because of its lower solubility.

A warning should be sounded concerning the danger of boron compounds to valuable ornamental plants or commercial orchards. The common varieties of citrus fruits, deciduous fruits, grapes, and nuts are all so sensitive to boron that it should not be used near them. Certain ornamentals also come within the list of sensitive species. On the other hand, where there is no danger to valuable plants, the sterilizing mixture mentioned above can be used with considerable satisfaction on graveled drives and parking areas, schoolgrounds, or roadsides. Hours of hand hoeing and weeding can often be avoided by a simple chemical treatment.

OTHER HERBICIDES

Many chemicals have been used in weed control at various times, and new ones are frequently proposed. The most useful have already been discussed, but a few others tested will be considered briefly.

Ammonium thiocyanate has recently been advocated for weed con-

trol. In our tests it proved ineffective as a translocated spray. In the soil it was less toxic than chlorate and did not leach readily. Though more expensive than arsenic, it was less persistent for soil sterilization. There appears to be no logical place for it in chemical weed control in California.

Calcium Chloron, a proprietary mixture introduced about three years ago, proved worthless as a weed killer.

Ethylene dioxide, proposed in the East for weed control and tested in barberry eradication, is expensive, extremely difficult to handle in the field, and not available in quantities.

Atlacide and other proprietary mixtures containing sodium chlorate are, according to workers, effective in proportion to their sodium chlorate content. In no case reported have the diluting or adulterating chemicals marked herbicidal properties. In soil treatment they have no known value. The cost to the user of any one of these materials should be related to the percentage of sodium chlorate in it.

Many arsenical "weed killers" are sold. In almost every instance these are sodium arsenite solutions whose value is determined by their content of arsenite trioxide. By comparison on this basis they will often be found to be excessively expensive. The simple formula given on page 31 can always be used in making up a sodium arsenite solution and usually insures considerable saving.

EQUIPMENT REQUIRED IN APPLYING CHEMICALS FOR WEED CONTROL

The common herbicides, applied by means of spraying equipment, may be divided into two groups according to their corrosive nature. Such noncorrosive liquids as Diesel oil, sodium arsenite solution, and sodium chlorate solution may be applied with any pressure spray machine. For small operations the diaphragm-pump knapsack sprayer of the Vermorel type is satisfactory (fig. 11). The wheelbarrow and barrel types used in orchards are better where two men are available, and the power orchard sprayer is most suitable for large jobs (fig. 12). Many special equipments have been built for weed work. These are usually fitted with an all-bronze pump and mounted on a truck. They may be fitted with hand guns for spot work and boom equipment for roadsides or open field (figs. 13 and 14).

Although the acid arsenical spray solution contains 5 per cent sulfuric acid, the inclusion of sodium arsenite so greatly reduces its corrosive action that this chemical may be handled in ordinary orchard spray equipment. The pump should have bronze-lined cylinders; since porcelain is etched by the acid, pumps lined with it may be ruined. All-

Fig. 11.—Vermorel knapsack sprayer; equipped with Brown pop valve, 22-inch brass extension, and Chipman nozzle, for weed work. The pressure gage is not needed for ordinary spraying.

Fig. 12.—Power spray rig, showing two lines of hose with multiple nozzle. (From Ext. Cir. 54.)

Fig. 13.—Power spray rig, built for roadside spraying. Will spray a strip 15 feet wide. Capacity, 900 gallons. (From Ext. Cir. 54.)

Fig. 14.—Power spray equipment adapted for spot work along roads. Two lines of hose. (From Ext. Cir. 54.)

brass plumbing, too, is best, though not absolutely necessary; a boom equipment made of ordinary steel pipe was used for three years at Davis without corroding through.

For corrosive chemicals, like dilute sulfuric acid, the special equipment mentioned before (page 25, and fig. 4) has proved satisfactory. It can be attached to any ordinary spray rig capable of supplying a steady flow of water at a pressure of 200 pounds per square inch. It consists of a container for the acid, the ejector for mixing acid and water, a boom for applying the spray solution, and the framework and plumbing necessary to fit it to the spray machine. All plumbing should be of brass; steel pipe is rapidly corroded by the dilute acid.

Some time has been devoted to a study of spray nozzles and a nozzle commonly used for spraying potatoes was adapted to weed spraying.[10] It delivers a flat, fan-shaped spray, giving uniform coverage.

As supplied by the manufacturers, these nozzles were not particularly uniform, especially as to the angle or spread of the fan. Since an even coverage is essential in boom spraying, slight changes were made in the design of the disks used in these nozzles. The improved disks deliver the spray at a uniform spread of 60° and have been calibrated for various standard drill sizes so that any desired delivery rate can be produced at will.

The market offers at present no special equipment for applying dry chemicals in soil sterilization; but any fertilizer drill that will spread the necessary amounts evenly over the ground should suffice. All plots used thus far have been treated by hand, a method fairly satisfactory for small areas. For somewhat larger areas a lawn-fertilizer spreader has been used, though difficulty was experienced in obtaining a uniform coverage, especially on sloping ground.

Equipment for both small-scale and large field application of carbon disulfide has been designed by the manufacturers of this material. They sell hand equipment at a nominal cost and rent machine-drawn equipment for larger areas. They also offer advice on the proper time and rate of application of this material.

[10] This nozzle, termed the "Hummer," is manufactured by the Friend Mfg. Company, Gasport, New York, and may be purchased from this company or from the Chipman Chemical Company, Palo Alto, California. Similar nozzles may be obtained from the John Bean Mfg. Co., San Jose, California.

SPECIAL PROBLEMS

California has many special weed problems resulting from infestations by species not common to other localities, from special effects related to our deep, fertile soils and mild winters, and from conditions related to our speciality crops and irrigation farming. Some of these problems are peculiar to California agriculture and have never before been subject to scientific investigation. Others have been studied in more detail here than elsewhere. A number of these problems are presented here along with such information, aiming toward their solution, as has been gained. Although each represents a special situation requiring special technique, it would be well for the reader to consult the sections on weed characteristics and principles of weed control in connection with the discussion presented.

WEEDS IN UNCROPPED AREAS

Throughout the state, weeds grow in profusion on ditch banks, on levees, along fence rows, roadsides, and driveways, and on vacant lots. Growers cannot expect to gain the benefits of cultural or chemical methods of weed control in farmed fields unless a concerted effort is made to prevent the growth and seeding of weeds in the uncultivated areas surrounding their farms.

Weeds of all classes—annual, biennial, and perennial—may be found in these noncultivated areas; but, as a rule, annuals predominate. This fact should somewhat simplify the problem of control. The pests must be destroyed before they mature seed. All too frequently, along roadsides or elsewhere, they are mowed when in seed and left on the ground to dry. Then entire plants or seeds are blown in great numbers to adjacent cultivated fields or orchards. Often farmers erroneously suppose that if the plants are mowed when in flower all danger of seed production is past. Many plants form flowers over a period of weeks; and, although the plant may appear to be in flower, it may mature seeds even when cut near the ground line. Consequently, early destruction is advisable if seeding is to be prevented.

Mechanical Control.—On all uncropped areas where a tractor or cultivating implements can be moved, clean cultivation with disks or plows will usually give the cheapest and most effective control.

Mr. A. E. Mahoney, Agricultural Commissioner of San Joaquin County, who has demonstrated the practicability of roadside weed control by means of tractor disks, makes the following statement:

Roadside weed control with tractors and disks is now an established operation in San Joaquin County. Control of weed pests and fire prevention are the primary purposes. The cost is much lower than the cost of oiling and burning.

The disking of roadsides was first started in the spring of 1931, with a caterpillar tractor and a 5-foot offset disk. Since then two more tractors and disks have been purchased, one by this office and one by the county highway-maintenance department. The work has proved so satisfactory that the purchase of three additional tractors and disks for the 1936 season is contemplated, making a total of six implements for roadside weed control. When not used for this purpose the tractors are employed in other road-maintenance work.

Fig. 15.—A puncture-vine-infested roadside after disking, San Joaquin County. (Photograph by A. E. Mahoney.)

The original purpose of roadside weed control was primarily the eradication of puncture vine. Weedy roadsides make a harbor where puncture vine may grow and reseed unobserved, to be picked up and scattered by automobile tires. When roadsides are weed-free, however, the puncture vine, which starts growth after the winter and spring annuals are turned under, can easily be seen, sprayed with oil, and burned or gathered before the burs mature.

In 1935, 244 miles of roads were disked in the Manteca-Ripon-Escalon districts where puncture vine is prevalent (fig. 15). A second disking was made on 151 miles to destroy many weeds, especially summer annuals, which had started after the first treatment.

Roadside weed control also keeps down or eliminates infestations of Russian thistle, yellow star thistle, Johnson grass, Bermuda grass, and many other species of weeds that creep and blow over on the farmer's lands. Since the interest of the growers adjoining these roads has been aroused, much eradication has been accomplished. Farmers are removing miles of fence line to permit the control of weeds generally found growing in such places.

Farmers in grain districts, where puncture vine and other noxious weeds are not a serious problem, demand the same roadside disking for fire protection. This work is done early in the season, the main object being to turn under the winter and spring

annuals growing between the road and the fence line. Its effectiveness is shown by the fact that last year no fires originated on disked roadsides.

In 1935, 487 miles of roads were disked for fire protection and weed control (fig. 16), starting February 4 and finishing May 15. Because of an unusually wet spring, 183 miles of roads were disked twice, the second disking being done after a second growth of weeds.

Aside from weed control, the condition of our roads has been vastly improved from a highway-maintenance viewpoint. Unsightly piles of tin cans, discarded automobiles

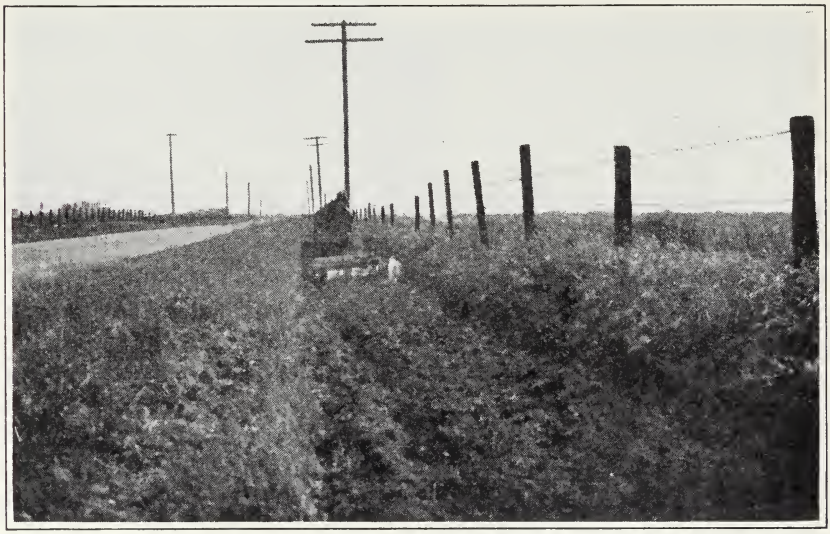

Fig. 16.—The disk is used to make a firebreak along a roadside, San Joaquin County. (Photograph by A. E. Mahoney.)

and their parts, broken-down fences, and other eyesores have been removed to facilitate disking. The general appearance of the countryside denotes thriftiness.

A total of 670 miles of county roads was disked in 1935 at an average cost of $7.57 per mile. Many of the roadsides were disked twice, and on some of the wider roads as many as nine rounds were made. For each 5-foot strip the cost was 72 cents per mile. This cost is considerably less than when the work was started, thanks to a general improvement of roadside conditions and added experience in the work.

It might be well to compare the cost of disking with that of oiling and burning. To apply Diesel oil, possibly our cheapest weed eradicator, at 4 cents per gallon and 300 gallons per acre, would cost $24.00 a mile per 8-foot strip for oil alone. To this amount must be added depreciation of equipment and cost of labor required in the application and burning. To treat the roadside from road shoulder to property line, as in disking, would cost approximately $75.00 per mile for the oil treatment as against an actual cost of $7.57 per mile for disking.

Chemical Control.—On areas difficult to reach with large equipment, chemical methods may be practical. Here consideration should be given to oils and sulfuric acid. These sprays, if used, should be first applied when the growth is only a few inches high, for then complete coverage

can be made at minimum cost. Moreover, the plants then are young and tender. During the season, several applications may be needed. The first year will naturally require more material than subsequent years because the soil contains innumerable seeds that will germinate. If, however, after germination the seedlings and other growth not killed by the first

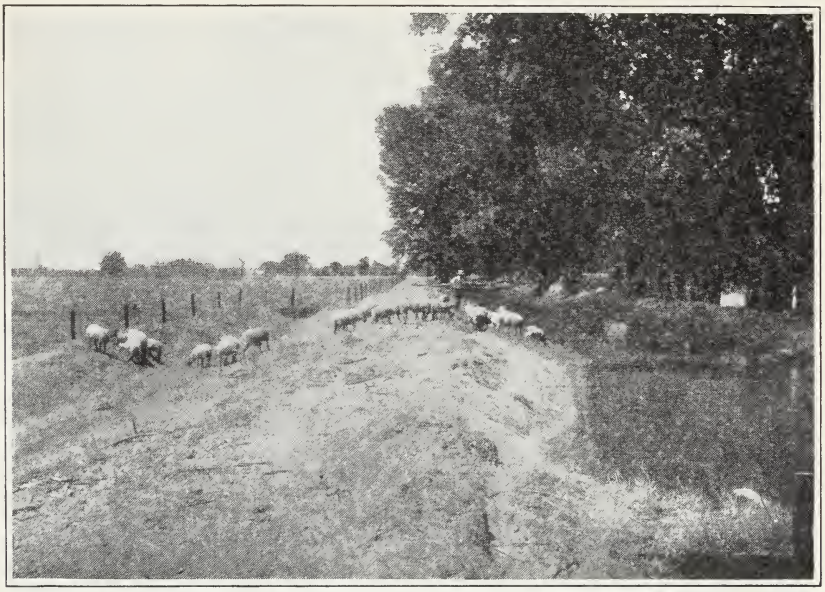

Fig. 17.—A ditchbank grazed with sheep. This is an effective and economical method of keeping weeds down along irrigation canals and ditches. (Photograph by A. E. Mahoney.)

spraying are sprayed again, the weed population is rapidly reduced. In most sections of the state, where the dry summers permit very little growth, one or two sprayings in a season will effectively keep down weeds on noncultivated, unirrigated areas. The cost should be somewhat smaller each year, for the vegetation to be covered constantly decreases.

Where more permanent results are desired, soil sterilization as described on pages 38 to 42 may be used. This is usually the most economical practice on areas which cannot be reached with cultivating tools.

Burning.—Since burning of dry weeds does not kill all the seeds, particularly those that have been shed, it produces no permanent benefits. Though useful in reducing fire hazard and in freeing ditches of weeds that hinder the flow of water, it accomplishes little from the standpoint of weed control.

Burning of green weeds is too slow and costly to justify the work required. In the first place, grasses can scarcely be killed thus on a practical scale. Whatever killing is done could be accomplished by other

methods with considerable saving of time and labor. Burning of areas treated with contact oil is recommended to remove the unsightly growth and reduce fire hazard.

Grazing.—A very effective and economical way of keeping weeds down along irrigation canals and levees is by grazing. Sheep are especially useful for this purpose. The animals not only keep the banks free of weeds, but they compact the soil, making it difficult for gophers to work. For four successive years a main irrigation canal on the University Farm has been grazed with sheep (fig. 17). In 1931 this canal was grazed 3,514 sheep-days, the total gain in weight of animals being 765 pounds; in 1932, this same canal was grazed 3,929 sheep-days, the total gain in weight being 908 pounds (during 9 days, no weight taken). No data were taken for 1933 and 1934. This particular ditch in years past has been covered with a heavy growth of weeds, the seeds of which were scattered to other parts of the Farm. Grazing has kept the banks clean, and eliminated this area as a source of weed seed.

WEEDS IN GRAIN FIELDS

The weeds that infest grain fields are many. In number, as well as in kind, they vary with the district and the conditions of culture. They consist largely of winter annuals, though some perennials occur.

Most of the grain in California is grown on unirrigated land; and the weeds, competing with the grain crop for moisture, plant food, and light, invariably reduce the yield. In addition, weeds increase the cost of harvesting, cleaning, and preparing for ultimate consumption.

Common Weeds Occurring in Grain Fields.—Among the weeds most common in grain fields are wild oats, several species of mustard, wild radish, common spikeweed, and buckthorn or fiddleneck. Thistles, such as the spiny sow thistle and the milk thistle, occur in many sections. Napa thistle or tocalote has spread throughout the state and yellow star thistle is present in the central coast region and in the Napa and Sacramento valleys. The few perennials that occur, such as morning-glory and creeping mallow, rarely cause much trouble except on land frequently fallowed.

Introduction and Spread of Weeds in Grain Fields.—Aside from the natural agencies of dissemination, there are two other potent means of spreading the weeds of grain fields. One is the common practice of buying seed "over the back fence" or from a neighboring district without ascertaining that it is free from weeds or cleaning it before sowing; the other is the custom harvester that moves from ranch to ranch, from infested field to weed-free field, without being cleaned.

Annual weeds, once started in a field, spread rapidly, especially on

land cropped every year. Most winter annuals, such as wild oats, mustard, and wild radish, ripen their seed before the grain crop ripens, or at the same time, so that their seed is shed or scattered by the combine in harvesting the grain. Others, like the star thistle and the Napa thistle, do not usually mature their seed until after the harvest; such seeds on maturity drop to the ground and maintain the infestation.

Control of Weeds in Grain Fields.—Control of the annual weeds in grain fields is mainly a cultural problem. Some farmers keep their fields fairly free by delaying plowing until January or later; this gives the weed seeds a chance to sprout, so that the young plants may be plowed under. This practice, if followed consistently, will normally keep the crop free from weeds; but late seeding in many of the grain-growing sections often results in low yields. Another practice, common where the land is fallowed every second or third year, is to delay plowing for the fallow until March, when all weeds and volunteer grain have started and can readily be destroyed by plowing. Since little rain falls after the land is plowed, the subsequent growth of weeds is usually negligible. This practice, however, is a poor one because it largely nullifies the benefits of the fallow—namely, moisture conservation and the stimulation of nitrification.

Occasional fallowing is fairly effective, as a rule, in controlling or eradicating wild oats, the seeds of which remain viable for only two or three years; other weeds, however, such as mustard, wild radish, and fiddleneck, whose seeds may remain viable for many years, are less easily eradicated. Late winter or spring seeding, though undesirable, may be necessary for weed eradication if the infestation is heavy.

A satisfactory procedure is to delay plowing or cultivation in the fall until most of the weed growth has started. Then, after plowing, two or three weeks should elapse before the seed bed is prepared and the crop seeded. This delay permits germination of the weed seeds that have been turned up, and the seedlings can then be destroyed with surface tillage implements just before seeding. Replowing just before seeding is undesirable, for it brings to the surface a fresh supply of weed seed to sprout with the grain. During the fallow year tillage should be followed, although the first plowing might be delayed until January or February in order to give the weeds a start. After plowing, two or three cultivations during the spring will destroy large numbers of weeds and will stimulate germination of the seed in the plowed layer. This practice, though more costly than delaying the plowing till spring, destroys weeds more effectively.

In one section of the state (fig. 18) Russian thistle has been combated by cutting and burning on stubble or summer fallow.

Chemical Control of Weeds in Grain Fields.—In the eastern and mid-

dle-western states, as in certain grain-growing sections of Europe, mustard and other broad-leaved annuals in young grain are often sprayed with chemicals. In this country iron sulfate ("copperas") solutions, varying in strength from 5 to 20 per cent, have been used. In tests this spray was most successful if applied when the weeds were small, with not more than four to six leaves, and when the atmospheric humidity was high. Injury to grains or other grasses was negligible. The sulfuric

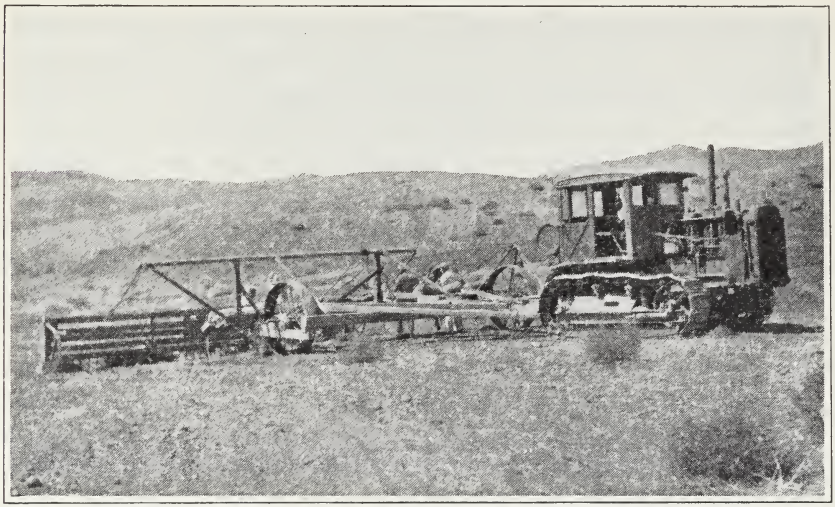

Fig. 18.—Equipment employed on Carisa plains in the campaign to control Russian thistle in grain fields. The tractor-drawn equipment carries a set of knives which cut the thistles at the ground-line, and a cradle which drags the weeds into windrows. Later the thistles are burned. Used principally in stubble or summer-fallowed fields.

acid method of controlling weeds in grain fields, and practical equipment for its use, are described on pages 24–27. It seems likely that this method will have wide application.

Perennial Weeds in Grain Fields.—As already stated, morning-glory and other perennials that make their growth during the summer usually spread more rapidly on fallowed land than on land continually cropped, because in the fallow year the moisture conditions are ideal for the growth of the weeds. On land fallowed every second or third year such perennials, once started, may soon occupy the whole field.

Perennials must be prevented from producing seed, for while some spread does occur because of the rootstocks, the greatest spread comes from dragging the mature vines, loaded with seed, over the field. When grain land is badly infested, its value will perhaps not justify the attempt to eradicate deep-rooted perennials by present expensive methods. Where small areas occur, weeds can and should be prevented from

spreading. As already stated, perennials should be kept from going to seed, then allowed to make a good vegetative growth in the fall, and sprayed heavily with a chlorate spray in October and November. The treatment should be repeated each year until the pest is eliminated. It will probably sterilize the soil for some time; but if the area is not large and the weed is finally eradicated, this temporary sacrifice is justified.

WEEDS IN ALFALFA

As to their effects upon the alfalfa crop, weeds fall into three groups: (1) Weeds that appear in the new seeding of alfalfa and threaten to choke out or compete seriously with the young plants. These weeds are mainly the annual, herbaceous, broad-leaved plants such as pigweed, mustard, Russian thistle, bur clover, and certain grasses. Such perennials as morning-glory and creeping mallow may also interfere with the growth of young alfalfa, especially that of late spring seeding. Alfalfa seeded in the fall or early spring ordinarily suffers but little. (2) Weeds that appear in the older fields and compete with the crop for plant food, moisture, and light. These may materially reduce the quality of the hay. Of greatest concern to the grower are foxtail, Bermuda grass, brome grass, crab grass, and water grass. Johnson grass, too, where prevalent, may be troublesome. In certain older fields, hoary cress and Russian knapweed may appear in dense patches; they are especially objectionable in hay. Although other weeds may occur in certain districts, those mentioned are most prevalent. (3) Parasitic weeds, such as dodders, that prey on the alfalfa and reduce or completely destroy the plants. Of several species, the small-seeded dodder is most common in California.

Weeds that Interfere with Establishment of Stand.—Control of weeds that may interfere with the establishment of a new stand consists primarily in eliminating as many as possible before the alfalfa is seeded and in providing favorable conditions for the growth of the alfalfa. Preceding the alfalfa with a cultivated crop will eliminate many weeds. Sudan grass, if irrigated, will smother most annuals before they have an opportunity to produce seed. A weedy field should be plowed several weeks before the alfalfa is seeded and should be irrigated, if necessary, to provide favorable conditions for weed growth. Then, just before seeding, the seed bed should be prepared, and the weed growth destroyed with as shallow tillage as possible. Shallow cultivation at this point is important in order to provide a good seed bed for the alfalfa and also to avoid bringing a fresh supply of weed seeds to the surface. Handled in this way, a clean stand of alfalfa can usually be obtained by seeding in early spring, when most of the winter annuals have started and are readily destroyed, and when moisture and temperature conditions favor

the rapid growth of the alfalfa. The same procedure is advisable for fall seeding, though elimination of weeds is then usually not so easy, because the time available for germination and destruction of the weeds is shorter, and the conditions are less favorable to alfalfa.

If a heavy growth of weeds starts with the alfalfa, keep it clipped back, allowing sunlight to reach the alfalfa plants. Weeds on a new field of alfalfa should always be cut high, 3 inches or more from the ground; young alfalfa plants grown in the shade are slender and spindling, with but few leaves. If cut off close to the ground, with most of the leaves removed, many of them will die.

Weeds in an Old Stand of Alfalfa.—When a good stand of alfalfa has been obtained and the conditions for growth are favorable, weeds seldom cause much trouble for the first two or three years. Thereafter, however, the stand becomes thinner, and weeds fill the vacant spaces. The general belief that the weeds cause the thinning is only in part correct. A dense, vigorous growth of alfalfa can normally hold its own, and only when space has been provided do the weeds come in and cause trouble. This may not be true of Bermuda grass and hoary cress, which appear actually able to crowd out the alfalfa. On the other hand, when soil-moisture conditions are good, excellent crops of alfalfa are sometimes obtained despite a dense undergrowth of these weeds.

The winter annuals, once started, spread rapidly and soon occupy all vacant space, making their most rapid growth while the alfalfa is practically dormant. A bad infestation may greatly stunt the spring growth by robbing the crop of plant food and moisture, and may in addition render the first cutting of hay almost worthless.

Many alfalfa growers have attempted to reduce the winter annuals by cultivation, the only known practical method. This procedure has usually met with but little success, because the job has not been done thoroughly and at the proper time. The spring-tooth harrow is the best implement, and the cultivation should take place in late January or February after the weed growth is well started. The field must be gone over repeatedly until all the weeds are dug out. Going over it once, as is usual, will rarely remove all the weeds and is often wasted effort. The drastic cultivation necessary to destroy the weeds will, obviously, injure many alfalfa plants; but given favorable conditions most of them will recover and grow much more vigorously than with the weeds present. The only condition under which cultivation may not be advisable is where such diseases as bacterial wilt and crown wart are present, for the cultivation, by injuring the plants, facilitates the spread of these diseases. Recently attempts have been made to control winter annuals with chemical burners; the results promise well if suitable equipment is developed, though the method is still in the experimental stage.

Most of the summer annuals, such as crab grass and water grass, occur only where the soil is continually moist. They are troublesome, therefore, only in fields where unfavorable soil conditions necessitate two or three irrigations per cutting. Attempts to eradicate such weeds by heavy summer cultivation have been unsuccessful, being apt to injure the alfalfa. The best remedy is crop rotation, or correction of the unfavorable soil condition, to lessen the need of frequent irrigation.

Bermuda grass is the weed pest most troublesome to alfalfa in many sections of the state. From small beginnings it spreads in ever widening areas until in a few years it may occupy the whole field and greatly reduce the yield of alfalfa, which can compete with it successfully for plant food and moisture only under the best conditions. The Bermuda grass cannot be removed economically; the only practical remedy is crop rotation. An alfalfa field badly infested with Bermuda grass rarely repays cultivation; the best procedure is to plow it up and eradicate the pest. After shallow plowing in August or September, all the Bermuda plants being carefully cut off and the exposed roots left to dry and perish, the field should be left without further treatment until late fall or early winter, when it should be deeply plowed in preparation for future crops. Two or three years should elapse before again seeding to alfalfa, and the summer crop should be one that permits cultivation and the destruction of such Bermuda as reappears.

Parasitic Weeds in Alfalfa.—The dodders are typical plant parasites. Starting from seeds, the yellow, leafless vines soon attach themselves to the alfalfa plant; then their roots die, and they grow entirely by extracting nourishment from the host. From a local infestation, the parasite spreads rapidly by the elongation of its stems. Appearing usually in rapidly spreading spots, it greatly reduces the growth of the alfalfa plants, seriously injuring the stand.

Of the various species of dodder, the small-seeded is the most prevalent in California, although others occur. One species, prevalent on native vegetation, will also attack alfalfa; but apparently it does little damage.

Dodders are good examples of seed-borne weeds. The pernicious species are nearly always introduced into the fields at a time of seeding. For this reason dodder is emphasized as an impurity in alfalfa seed. The parasite, after appearing in fields, produces abundant seed, which may remain viable in the soil for many years. Rotation for several seasons is, therefore, usually necessary to eradicate bad infestations but lighter ones are easily remedied, preferably by spraying the areas with oil or kerosene, and burning. This is better practice than mowing before treatment, for it involves less danger of spreading the dodder with the mower

or scythe. In young stands the alfalfa plants may also be destroyed in this way, but in stands a year old or more they will not be injured. The spots should be carefully watched for reinfestation. In bad cases the best procedure is to plow up the alfalfa and rotate with other crops for two or three years.

WEEDS IN ORCHARDS AND VINEYARDS

Weeds in orchards and vineyards may not be evidence of careless farming, nor are they always an unmitigated evil. In fact, certain annual weeds are employed as covercrops and may even wisely be allowed to come into seed. Pernicious annuals, however, such as Russian thistle and star thistle, should not be allowed to come into seed in orchards or vineyards, but should be plowed under or disked in. Such annuals employed as covercrops, though relatively harmless to the orchard, may endanger adjacent cultivated fields. Perennials, on the other hand, particularly morning-glory, hoary cress, Russian knapweed, Bermuda grass, and Johnson grass, should not be allowed to gain headway in an orchard or vineyard nor be employed as covercrops; they provide a too dangerous source of infestation.

The most important purpose of cultivating orchard and vineyard soils is to remove weed competition, as Veihmeyer and Hendrickson have emphasized.[11]

Different experiment stations have attempted to measure yields on tilled and untilled plots. Areas in which weed growth has not been a factor show no increase that can be attributed to stirring the soil. In fact, the conclusion that cultivation is needed only to remove weeds is almost unanimous.

Many fruit growers, therefore, have materially changed their methods of soil management during the past several years and have allowed weeds to grow for long periods. Considerable saving has resulted because much less frequent cultivations are given and tillage is shallower than formerly. It must be pointed out, however, that weeds in an orchard or vineyard may compete so seriously for water and soil nutrients as to make their removal imperative. In the eastern states, as well as in England, sod has sometimes proved very injurious to orchards, probably through the depletion of nitrates, which should in such cases be added to the soil.

Weeds often harbor insect and fungus pests and may, in orchards and vineyards, cause infestation of neighboring crops; consequently clean cultivation, even though unnecessary to conserve moisture, may be needed to destroy the weed hosts of pests.

[11] Veihmeyer, F. J., and A. H. Hendrickson. Essentials of irrigation and cultivation of orchards. California Agr. Ext. Ser. Cir. 50:1–24. 1930.

Evidently, as far as weeds are concerned, cultivation in orchards is advisable and perhaps necessary when weed growth becomes a serious competitor for soil moisture, when pernicious weeds threaten neighboring fields, and when the weeds harbor dangerous insect or fungus pests.

For the control of morning-glory and other perennials, see the sections covering these specific topics. The acid arsenical solution, either as a spray or in jars, may be used in orchards without injury to trees, vines, or soil. The jar method is particularly applicable to small patches of morning-glory. Wild blackberries in orchards often give trouble. Usually the cheapest control method for these is to remove the top growth, plow or grub the plants, and work the area over carefully for several seasons. The top growth may be killed by spraying with Diesel oil, and burning. The chlorates and carbon disulfide, if used at all, must be applied cautiously for they may seriously injure trees or vines.

WEEDS IN LAWNS AND GOLF GREENS

The eradication or even the control of weeds in lawns and golf greens is exceedingly difficult. At the outset, extreme care should be taken to plant the lawn in a well-prepared seed bed and with the best and purest grade of lawn-grass seed available. Often many weed seeds are introduced into a lawn at the time of seeding. The variety or mixture of grass should be well adapted to the soil and climate of the locality. Except in very fertile soils, a light application of nitrogenous fertilizer should be made during the preparation of the seed bed to help the young plants become established. Once a solid turf has been formed, if it is kept thrifty by proper watering, regular mowing, and fertilizing, weeds have difficulty in invading it.

Many of the weeds that are troublesome in lawns have special characters that enable them to grow and spread in spite of competition by the grass and frequent cutting. They either have very short stems, forming rosettes of leaves near the surface of the soil, or they spread by rootstocks or runners near the surface. Common weeds of the first type are: dandelion, plantain, shepherd's purse, and chicory. Spreading lawn weeds are: crab grass, Bermuda grass, knotweed, chickweed, speedwell, oxalis, creeping buttercup, field madder, bur clover, and spotted spurge.

If any of the above-named weeds appear in a newly planted lawn they should be pulled while the soil is moist so that all roots are removed. Any of them, if allowed to become established, will crowd out the grass and eventually ruin the turf. The best time to eliminate them is while they are young.

Because of their excellent means of seed dissemination, most lawn

weeds are able to invade relatively clean and well-established lawns. The maintenance of a lawn in a weed-free condition therefore is a constant battle. Two methods are used in combating these pests in an established lawn. The first, and undoubtedly the best, is to keep the lawn so thrifty that only occasionally are weeds able to secure a foothold. Certain rules must be followed in proper care of a lawn. Mowing should be fairly frequent and regular but not too close. If too much leaf surface is removed the perennial roots of the grass become depleted of organic nutrients and annual weeds are favored.

Irrigation or watering should be ample to provide for the needs of the grass but not in excess. Frequent heavy watering leaches nutrients from the soil and favors the growth of plantains, dandelions, and annual grasses. Plant nutrients should be amply provided. In many places it is becoming the practice to leave the clippings on the lawn. They are soon hidden from view in a thrifty lawn and depletion of the sod is prevented. Where this practice does not induce other problems, such as fungus diseases or insect pests, it seems to be thoroughly sound.

Under the most favorable conditions, however, a lawn needs occasional fertilization. A good grade of well-rotted manure, free of weed seeds, is undoubtedly the best material for this purpose. The viability of weed seeds in manure is destroyed if it has been well rotted. If such manure cannot be obtained, use some other organic fertilizer such as cottonseed meal, fish meal, blood meal, or guano. These materials must be applied sparingly and are best used during the fall or spring in California. For quick stimulation during the growing season, ammonium sulfate may be used. Its effects, however, are not so lasting as those of the organic materials.

Weeds appear only occasionally in a healthy lawn and they should be pulled or removed with a long-bladed knife, spud, or chisel. All roots must be removed or they will sprout and grow again. Dandelions and plantain have been known to send up shoots from a depth of 3 inches or more.

Chemicals have been used against lawn weeds with varying success. Spot treatments may be made with gasoline, kerosene, Diesel oil, carbon disulfide, sulfuric acid, sodium arsenite, iron sulfate, ammonium sulfate, or any other toxic compound. The dosage must be adapted to the weed in question and the type of herbicide. With the oils, about a teaspoonful per plant is sufficient. Somewhat less of the iron or ammonium sulfate is required. A few drops only of the sodium arsenite or sulfuric acid are sufficient. Usually a small area of the turf is killed but it soon grows over. Where a large number of weeds are treated the whole area may require fertilizing and reseeding.

As a rule, the best procedure in treating an old lawn heavily infested with Bermuda grass, dandelions, and other weeds is to spade or plow it up, rake out the roots of weeds, fertilize well, and reëstablish the lawn. A small infestation of Bermuda grass, if detected soon enough before it has seeded, should be dug up to a depth of 12 to 18 inches, well beyond the limits of growth laterally, and the soil replaced with new soil. Carbon disulfide has been used to eradicate Bermuda grass in lawns and golf greens. This chemical may be applied by merely sprinkling the infested area with an ordinary garden sprinkling can, and immediately covering it with wet canvas. Use about 1½ gallons of carbon disulfide to the square rod. To keep the vapors of carbon disulfide from escaping, two individuals may work together, one applying the chemical, the other unrolling the wet canvas over the treated area.

Iron sulfate (copperas or green vitriol) has been successful in the control of dandelions and chickweeds in Rocky Mountain and eastern states. The spray solution is prepared by dissolving 1½ pounds of the chemical in each gallon of water. It is best applied with a knapsack sprayer of brass. As a fine mist, one gallon of the spray solution will cover about 40 square yards of lawn surface. From four to six applications in one season are required to completely kill dandelions. The lawn should not be watered until the weeds have been severely affected, usually a period of 24 hours.

Although the grass may also be injured, it soon recovers with no permanent damage. The weeds, being broad-leaved, suffer more severely than the grass. After several treatments, food reserves in the roots of weeds are depleted and they are unable to survive the winter. Young dandelions are destroyed with fewer sprayings, and broad-leaved annuals are usually killed with the first application. Warning should be given that iron sulfate is strongly corrosive and in addition will leave rust stains on buildings, cement walks and curbs, and on clothing.

Oxalis is one of the most difficult weeds to control in California lawns. In addition to having a means for throwing its seed a distance of several feet as they mature, it forms small, underground tubers which enable it to spread vegetatively. Every effort should be made to prevent it from becoming established in a lawn by digging up each small plant that appears. Once it spreads in a lawn, heavy fertilization should be practiced. If this fails, spraying in the fall with sodium chlorate at a rate of 3 pounds per square rod will give a temporary sterilization. If plants appear again in the spring, respray. Then the lawn may be leached free of chlorate, fertilized, and reseeded.

Crab grass, a creeping annual which roots freely at the nodes, requires constant watching. It forms an abundance of seed which lays

over and reinfests the areas during the following summer. It can be eradicated by careful digging as the new plants appear. If allowed to spread it can be killed by spraying with Diesel oil, a treatment from which the perennial lawn grasses recover. However, this leaves an unsightly sod which requires reseeding. In severe infestations it is probably best to dig up the sod, work down and water frequently, with cultivations to kill the seedlings, and reseed after the soil has been freed of the pest.

WEEDS IN DITCHES AND WATERWAYS

Weeds of ditch banks have been discussed to some extent under the heading "Soil Sterilants." Along cement-lined ditches, in certain soils, chemical treatment has been economical and effective in controlling weeds. Soil sterilants, however, are of no use below the water line of unlined ditches in any soil, and in the heavier recent alluvial soils they are required in excessive dosages above the water line. In such cases mechanical control seems best. Various mechanical methods are in use including plowing, disking, dragging, and hand hoeing. Figure 19 illustrates a piece of special equipment designed by Mr. W. F. Wooley, engineer for the West Stanislaus Irrigation District, and successfully used in that district for several years. The laterals in this district are of uniform shape and size and all outlets are of the inverted siphon type. For this reason this one piece of equipment can be used on all of the main laterals. In passing the outlets the tractor draws the disk up to within a few inches of the structure. Then a man on the disk (not shown in the picture) raises the gangs by means of the lifting devices, the tractor pulls ahead, and the disks are lowered again as the structure is passed. In this way only a few square feet of surface are left undisked at each structure, reducing to a minimum the hand hoeing required. This equipment covers many miles of ditch in a day and by going over the system several times each year the ditches are kept open for a free flow of water and devoid of weeds.

Ditches which carry water throughout the whole year usually harbor plants which are rooted in the mud or float on the surface of the water. Such weeds grow and spread rapidly, each year's growth accumulating upon that of the preceding until the flow is seriously restricted and dredging or other mechanical cleaning is necessary.

The only floating weed of any importance in California is the water hyacinth, a most pernicious perennial which, fortunately, has gained a foothold in only a few localities. The best control thus far found is spraying with sodium arsenite. However, if arsenite is used there is the possibility of poisoning animals which drink the water.

Common perennial weeds rooted in the bottoms of ditches are cattail, tule, and yellow water weed. Control of these by chemical sprays has seldom been attempted. Some ditches under observation have been

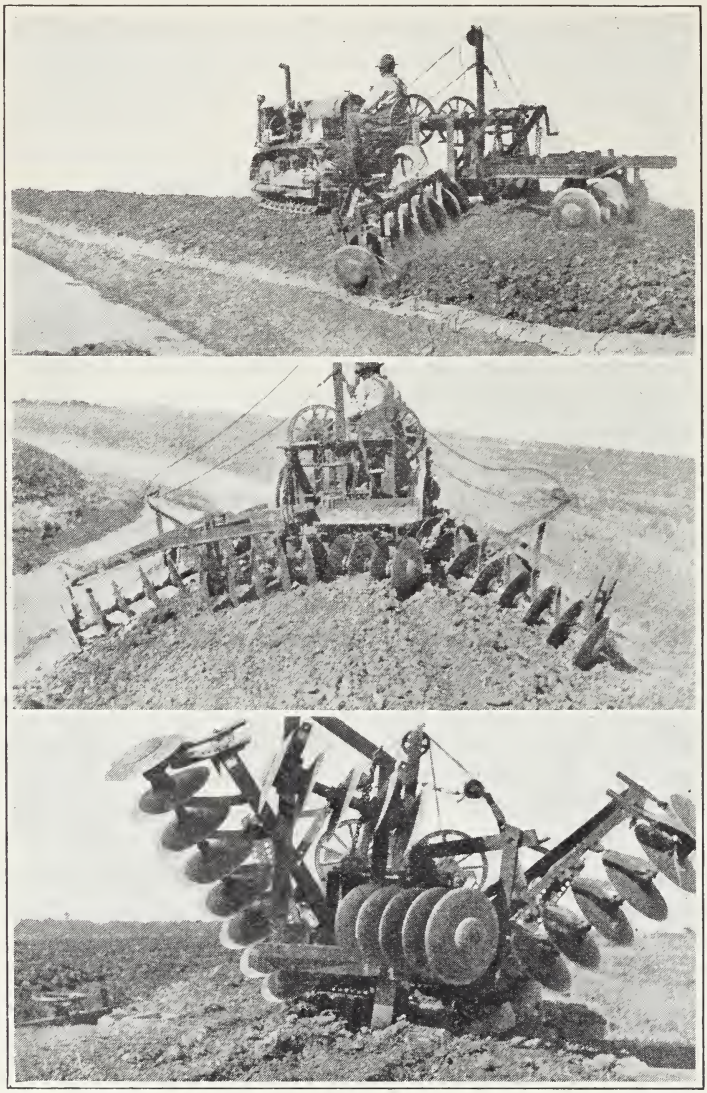

Fig. 19.—Three views of the special ditch-bank disk used by the West Stanislaus Irrigation District to control weeds on their laterals. The upper two views show the machine in operation. The lower view shows it passing an obstacle with the disk gangs raised.

sprayed with oil, a method that deserves careful trial. These particular ditches were sprayed three times the first year, twice the second, and once or twice the third. Although oil does not penetrate roots and root-

stocks, it does destroy top growth; thus, if applied persistently, it weakens and may ultimately kill the underground parts. Weeds growing in the water are apparently difficult to eradicate with herbicides; but, even so, such chemicals may be cheaper than dredging or pulling.

A drag-chain, with links made from 1 or 1½-inch material, has sometimes been effective in keeping down cattails and tules in ditches. This

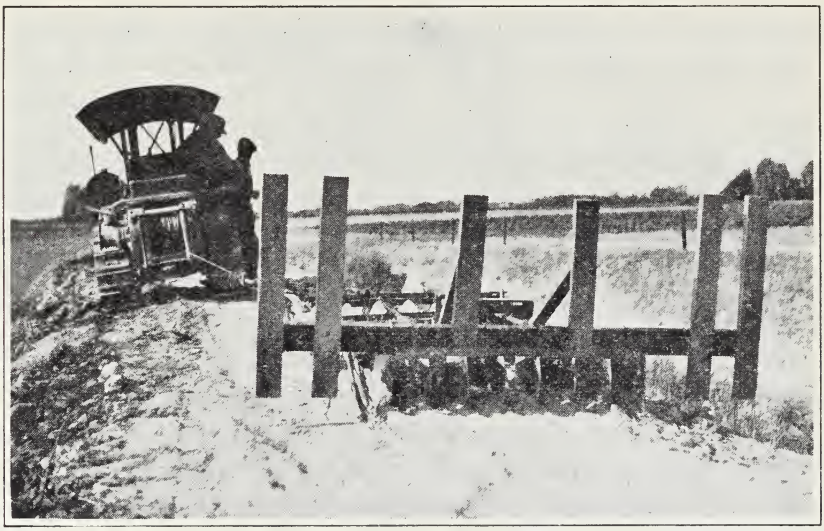

Fig. 20.—Equipment used by the Turlock Irrigation District for cleaning drainage ditches.

chain is dragged along the bottom of the ditch in one direction and then back, thus bending over and breaking the stems of the weeds. The operation is repeated as often as is necessary to keep the cattails and tules from clogging the ditch. The weeds, though not eradicated the first year, are weakened so that the later treatments may be less frequent; eventually the ditch is kept clean at a very low cost.

Ditches up to 10 feet in width can be dragged with one team, by using a long stretcher and having one horse on each bank. On larger ditches one team is required on each end of the chain. This is probably the most inexpensive method for controlling tules and cattails. In order to be effective, however, the dragging must be done several times during the summer. A single cleaning in the spring is beneficial but has no permanent effect upon the roots of the plants.

The Turlock Irrigation District has used the equipment illustrated in figure 20 for cleaning drainage ditches. The equipment now in operation consists of a Diesel-powered Caterpillar 40 with a Willamette-Ersted "Hyster" power towing winch and a 6-foot Killefer offset disk with

22-inch blades. The disk has been reinforced throughout and an accessory hitch built on so that it can be pulled from either end. The attachment shown in the picture acts like a buck-rake to gather the plants which have been cut off by the disk and facilitates their removal from the ditch.

By adjusting the length of cable and degree of offset of the hitch it is possible, working from one side, to disk and remove the tules from both sides and the bottom of the ditch.

The tractor and power winch are also used for pulling willows where they occur. There is a hook on the end of the cable and when willows are encountered the disk is dropped and the cable is wrapped around the tree. The power winch is then used to pull the tree and drag it to the bank. Having disposed of the tree, the tractor backs up, the disk is picked up again, and the equipment proceeds with the cleaning operation. The Turlock District has found this equipment most valuable in the maintenance of their drainage system.

WEEDS IN RICE FIELDS

Because of the conditions under which rice is grown, the weeds in rice fields differ from those infesting other field crops. The most troublesome ones grow, like rice, in standing water. After the rice has been seeded, there is no practical means of combating the weeds; and as the rice requires a long growing season, most of the weeds mature and drop their seeds before harvest time. Consequently, weeds in rice fields multiply rapidly. Three years is, by common experience, about the maximum time a field can be cropped continuously with rice before becoming so weedy as to render the crop unprofitable.

The weeds most troublesome in the rice fields are varieties of water grass, red stem, scale grass or sprangle-top, red rice, spike rush, cattail, various species of umbrella plants or nut sedges, tule or bulrush, and arrowhead.

Up to the present, water grasses have been fought more vigorously than the other rice weeds. Yet the water grasses, though most prevalent, are by no means the most serious. Such perennials as the nut sedge, cattail, and spike rush, reproducing by underground parts as well as from seed, are much more difficult to eradicate when once established.

Water grass is of two or more types. The common type fruits abundantly, matures, and sheds its seed before the rice crop is ripe. It spreads and infests the fields rapidly. Fortunately, common water grass and also scale grass, or sprangle-top, can be controlled successfully by *keeping the fields flooded from the time the seed bed is prepared until the rice crop is mature.* Submerged under 4 to 6 inches of water, the seed of com-

mon water grass will not germinate. When, however, rice is drilled or broadcast and irrigated lightly for two to four weeks to bring it up before it is permanently flooded, shallow submergence at 2 to 4 inches apparently does not control the weed. The second type, the so-called "white water grass," matures somewhat later, at about the same time as the rice, so that when the crop is harvested most of the seed is removed from the field. Although, in consequence, it spreads less rapidly than common water grass, it cannot be controlled by flooding. Its seeds will germinate and produce plants with any submergence that will permit the growth of rice.

As none of the other important annuals can be controlled by flooding, the only known method of checking them is the periodic fallow now commonly practiced.

The perennials offer a more difficult problem. Nut sedge, for example, is spreading rapidly and, as it may reproduce either by seed, or vegetatively by the nut-like tubers, constitutes a real problem. It thrives equally well on moderately moist and on wet soil. Its vegetative mode of reproduction makes it extremely difficult to eradicate by cultivation.

Cattails, likewise, reproduce both vegetatively and by seed. In the field they can be controlled by proper cultivation; but a fairly dense stand, once developed, is not easily destroyed. Once cattails infest the land, heavy seeding with rice apparently does not control them; but a heavy stand of rice does tend to prevent their entrance. Plowing in the spring and thorough drying of the roots will destroy many plants. In fact spring plowing, with a well-prepared seed bed, aids greatly in the control of many rice weeds. Disked stubble does not, as a rule, provide a satisfactory seed bed. Such roots as remain in the soil will renew growth; and cultivation must usually be repeated two to three times during the season to be fully effective. Most perennials can be controlled by cultivation repeated often enough to prevent an appreciable development of the aboveground organs. The number of cultivations necessary and the time required will vary with the species. Judging from preliminary tests, cattails and some other perennial weed pests may be controlled with chlorate sprays; but the conditions necessary have not yet been fully worked out.

Destruction of weeds will not solve the rice-weed problem; equally important is prevention of their introduction. The weed seeds are introduced in three ways: with the rice seed, with the irrigation water, and by wind and other agencies, from plants growing on adjacent waste or unused land.

New weeds are usually first introduced into a district with the rice seed. Thus certain sedges now spreading in the rice area were brought

in with rice seed from the Orient. Red rice is, as a rule, also distributed with the seed. The use of clean seed is therefore important in preventing infestations.

Since most weed seeds float or are readily transported by flowing water, the seeds of weeds and grasses once allowed to mature on the ditch banks soon find their way to the irrigated land. Unsuccessful attempts to filter off such seeds from irrigation water by the use of screens have shown that the numbers thus transported are enormous.

RANGE WEEDS

Although many of the introduced plants now common on California ranges are weedy compared with the original vegetation, only those that tend to supplant species of definite feed value will be considered. Among the most common are Klamath weed, artichoke thistle, yellow and purple star thistles, and milk thistle. As a serious menace to the foothill and valley ranges of the state, these plants should be suppressed.

Although overgrazing has undoubtedly encouraged the spread of these weeds, their effective means of seed dispersal, and the wide natural variation in range cover due to the fluctuations in rainfall, render invasions almost uncontrollable, regardless of the rangeman's policy. These pernicious range weeds, all vigorous growers of little or no feed value, have a strong competitive ability. Many are perennials with a distinct advantage over the common annuals. In these cases, deferred or restricted grazing tends to favor the weed at the expense of the annual range plants. Eradication of large areas usually costs more than the land is worth.

Considering these points, the only feasible method in the lower ranges of California is, apparently, to check the range weeds when they first appear and to prevent their spread. Destruction of large areas of such species as Klamath weed will at best be slow and costly.

The rangeman should learn to recognize the more noxious range weeds and should make every effort to stamp out the first invaders. The unrestricted grazing of cattle from undetermined localities on public domain is bound eventually to cause infestation, providing a constant source of seed for further spread. The recognition and eradication of weed species are therefore increasingly important to stockmen, especially to those who use public ranges or buy stock that have used them. The chemical methods already described should check new infestations.

KEEPING FIREBREAKS CLEAR

As fire is a constant menace to the forests and watersheds of California, its prevention and control are all-important. The Forest Service has

developed a system of firebreaks throughout the mountain regions, especially in the southern part of the state.

Although these strips, cleared of small trees and other vegetation, may sometimes stop the spread of fires, they serve principally as a means of access to remote areas and as starting places for backfires. For this reason they are located along ridges wherever possible.

Experience during the present season has shown that in years of high rainfall the growth of annual species on these cleared areas not only reduces the efficiency of firebreaks but, unless they are promptly cleaned during the early summer, makes them more hazardous than the original trees and brush. Clearing by hoe labor, which has prevailed in the past, is excessively expensive under these conditions and, according to experiments, may be superseded by chemical soil sterilization.

In the absence of stock and game, sodium arsenite is the most practical chemical; applied at the rate of 4 pounds per square rod to a strip 6 or 8 feet wide through the middle of the break, it should prove of great value in backfiring. Where animals are grazing, a mixture of Colemanite and sodium chlorate may be used. Considering the high cost of hand labor, any chemical treatment good for several years and applied at a nominal cost should be of value.

Another problem on firebreaks and in cleared pasture areas is the killing of stumps. Here, again, chemical treatments are indicated. According to experiments by the California Forest Experiment Station, most of our sprouting species may be easily controlled by girdling at or below the ground level and treating the girdle with a solution of sodium arsenite containing 20 per cent As_2O_3 by weight. In the presence of livestock, the girdle may be made below the level of the soil and covered with soil after the arsenic is applied. If this is not practicable, a 20 per cent sodium chlorate solution or Diesel oil can be substituted for the arsenic. In either instance, observe all the precautions listed on pages 32, 35, and 41.

Stump treatments can be made at any season except spring. Sprouts appearing after treatment should be gone over again.

SPECIAL WEEDS

Often the peculiar environmental conditions under which certain weeds grow in California create special situations not encountered in other localities where studies on weeds have been made. For this reason there have been developed in this state methods not commonly used in weed control elsewhere. A few of these special situations are considered here under the names of the specific weeds. In all cases, however, the reader

should familiarize himself with the section "Principles of Weed Control" before considering the particular subject presented.

PUNCTURE VINE[12, 13]

Puncture vine has been known in California since 1903 but was probably introduced some years earlier. Having appeared first along the railroads, it spread rapidly with the increase of automobile travel. Although tires have been the principal means of dissemination, it is also carried by animals, by various crops and products, and by almost any other object with which it comes in contact.

Beginning about 1925, California counties made a more or less concerted effort at control, except in a few counties considered too badly infested. For several years the total amount thus expended averaged about $160,000 annually, mostly for spraying with chemicals, in addition to expenditures by the State Division of Highways, the railroads, and individuals. Since 1932, appropriations have been considerably reduced.

The damage done by puncture vine consists principally of mechanical injuries to persons and animals, increased operating costs in the production of crops, diminished value of land and of crop and livestock products, and limitation of markets for infested products. Though authentic cases of direct injury to livestock from the feeding of infested hay are rare, cows are said to fall off in milk production when first given hay containing large quantities of puncture-vine burs. A disease of sheep in South Africa is reported as caused by grazing on this weed. Contrary to a rather general belief, puncture vine injures very few tires except those light in construction or worn thin.

Germination of Puncture-Vine Seed.—The longevity of puncture-vine seed is not known. A plot on which no seed matured for eight years continued to sprout seed each season in undiminished quantities. When more than one seed is present in a bur, the uppermost usually germinates first; but given favorable moisture and temperature the others may germinate the same season. The seasonal growth is apparently correlated with soil moisture and temperature. Under nonirrigated conditions 90 per cent of the total number of plants for each season sprouted by July 15 on one plot observed. The total number sprouted was highest in those seasons when May and June were warmest, those being the only months when sufficiently high temperatures accompanied favorable soil-moisture conditions. Whereas summer rains increase the rate of germina-

[12] This section was prepared by Mr. Ethelbert Johnson, Deputy Agricultural Commissioner, Orange County.

[13] Johnson, Ethelbert. The puncture vine in California. California Agr. Exp. Sta. Bul. 528:1–42. 1932.

tion, fall rains, after the mean temperature has dropped, have no apparent influence; nor is the rate affected by the amount of winter rainfall.

The relation between temperature and germination was further established by laboratory tests. Burs incubated at relatively high temperatures showed a higher rate of germination than burs incubated at lower temperatures.

During the season of rapid growth, the period from blossoming to maturity of seed is very brief. Burs picked less than 10 days from the time of blossoming failed to germinate, but a large percentage germinated when permitted to remain on the plant 10 days or more after blossoming.

Apparently puncture-vine seed requires a rest period after maturity before germination will take place at a normal rate; but after the rest period germination is rapid. Burs of the current season, therefore, should be held at least six months before being tested for germination. When tested one or more seasons after maturity, more than 90 per cent of the total viable burs germinated within the first 3 days of incubation, and practically all germinated within 10 days. In tests made the same season the burs matured, germination could be induced only with difficulty in the first 60 or 90 days and was, in most cases, not completed for 200 days or more. If the plant is killed or the burs are picked before the end of the natural ripening, germination is accelerated, apparently by interruption of the physiological processes responsible for the rest period.

The approximate viability of puncture-vine seed may be estimated by inspection. If the burs are soaked overnight in water and cut open, the number containing apparently sound seed checks rather closely with a laboratory germination test of the same sample.

The treatment of products infested with puncture vine to make them acceptable in districts where the pest is under control has presented a difficult problem, especially with reference to bulky materials. Alfalfa meal from infested hay, milled by the ordinary process, contains viable seed; but if in the milling the meal is passed through a mesh not greater than $\frac{1}{32}$ inch, no viable seed remains.

Composting of infested manure is not a sure method of destroying puncture-vine seed. A test was made of the effect of decomposition of straw and other organic refuse in the making of artificial manure. Though seeds in the interior of the compost stack were destroyed, the exterior was not sufficiently decomposed to kill the seeds.

Control of Puncture Vine.—To control growing puncture vine, cultivation and cutting are satisfactory if done often enough to prevent seed formation. Heat from a weed torch or from live steam may be used, but

burning of green plants without previous treatment is considered too slow and too expensive. Although several chemicals will destroy puncture-vine plants, only certain petroleum products are known to kill the seeds in all stages.

Diesel oil is satisfactory and widely used for the purpose because of its availability, its low cost, its high proportion of aromatic and cracked oils, and its ability to emulsify satisfactorily with water when the asphalt content lies within the range of 2 to 5 per cent, which makes possible the use of a spray containing 50 to 75 per cent water in the oil. The effectiveness of oil in destroying seeds depends on the completeness of coverage and on the quantity deposited on the burs.

Soil may be sterilized with chemicals to prevent the growth of puncture vine.

The following methods are recommended for controlling this pest: First, treat with oil to kill the seeds, if present, without disturbing the vines. Whenever young plants appear, and before the burs form, cut off just below the crown; or spray with oil or any cheap chemical weed killer. During the summer, by frequent irrigation encourage the sprouting of seeds remaining in the soil.

MORNING-GLORY

The common or wild morning-glory, undoubtedly the most serious and most pernicious weed in California today, infests every county where agriculture is extensive. It invades our choicest land and, so far, has defied all efforts to depose it. Its presence may not necessarily be, therefore, an indication of poor farming.

Characteristics of Morning-Glory.—Morning-glory is a perennial that renews its growth from year to year from its underground stems and roots (fig. 2), and through the spread of these subterranean structures rapidly widens its area of infestation. Ordinarily it starts in a field from seed. Its rapid spread in the early years of farming in California was probably caused by the sowing of uncleaned wheat and barley seed. It is almost impossible to remove morning-glory seed from these cereals because of the similarity in seed size. Grain farming affords this pest an excellent opportunity to produce seed and thus to become established.

The root of the plant will, under favorable conditions, penetrate the soil to a distance of 20 feet or more. From the main root and shallow laterals, new shoots come to the surface, so that the plants spread vegetatively in an everwidening circle. The seed, being produced in abundance, rapidly increases the infestation and is in fact the most important means of dissemination. From a small area the pest can quickly be spread over a field by the tillage implements, which drag vines bearing

mature seed. The underground parts torn loose by the implements and carried for considerable distances may, if embedded in moist soil, also start a new infestation; but the spread in this way is small compared with the spread by seed.

Morning-glory seed probably retains viability in the soil for many years. Though data on wild morning-glory (*Convolvulus arvensis*) are not available, in trials with a closely related species, seed buried at depths of 8, 22, and 42 inches showed germinations of 27, 41, and 43 per cent, respectively, after 20 years. Where morning-glory has become established, therefore, one must not only destroy the established plants but also prevent recurrence from seed that has lain dormant in the soil.

Control of Morning-Glory.—Although morning-glory has received attention for many years, no completely satisfactory or economical method of control has yet been devised. As experiments show, the pest can be checked or almost completely exterminated, but only with a considerable expenditure of time, labor, and money.

Morning-glory has been attacked in several ways. Cultivation, smothering (either with a smother crop or with nonliving material), cropping methods, and chemical herbicides have been used with varied results. All these methods are useful, and often two or three may be combined. Pasturing and flooding have also been tried, with indifferent success; but such methods are, at best, applicable only under special conditions.

Control by Cultivation.—The numerous attempts to eradicate morning-glory by cultivation have met with some success and many failures. Poor results can be attributed to careless or incomplete treatment. The underlying principle in eradicating perennials by cultivation is that the development of the green leaves must be prevented. A second rule is to continue cultivation until the reserve food material is used up in new growth or until underground parts are starved to death. Poor results are usually attributable to failure to prevent leaves from developing, for even a small leaf surface will soon manufacture and store in the root sufficient food material to undo the effect of several cultivations. The best procedure is to cultivate at definite intervals, often enough so that no new shoots reach the light and to do the work faithfully. Just how often the field must be weed-cut depends on the depth of cultivation, the season, the amount of reserve food in the roots, and perhaps certain local conditions. With the ordinary depth of cultivation of 4 to 6 inches, the intervals cannot be more than one week; and during the summer heat, when growth is most rapid, cultivations must be more frequent.

During July and August, according to observations at Davis, shoots

from plants cut off at a depth of 16 inches will reach the surface in 10 to 12 days. Cultivation must begin in the spring as soon as growth starts and must continue until growth definitely stops in the late fall or early winter. On shallow soils or soils with a high water table, where all root development is near the surface, less time is required to eradicate morn-

Fig. 21.—One-horse weed knife, made by blacksmith.
(From Cir. 256.)

ing-glory than on soils that permit deep root penetration. Under the former condition, some farmers have reported eradication in a single season. At Davis, however, on a Yolo sandy loam soil, plants were still thriving and producing vigorous shoots after three years of clean cultivation. On the latter type of soil, morning-glory grows most luxuriantly, and eradication by cultivating is obviously slow.

The implement most suitable for cultivating morning-glory is the straight-blade weeder (figs. 21, 22, 23), kept sharp and in good cutting condition. The field should be plowed rather deep in the early spring, and the soil worked down thoroughly. If a deep layer of loose soil is thus provided at the start, the weed cutter can be run at the necessary depth more easily than if the plowing had not been done. When weed-cutting the field, the weeder must be lapped at least 18 inches to 2 feet to insure the cutting of all the shoots. Care and eternal vigilance are the price of success in controlling morning-glory by cultivation.

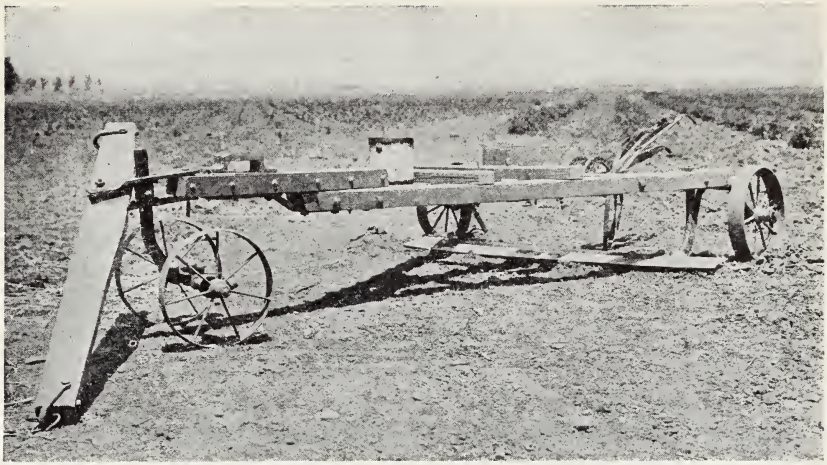

Fig. 22.—Three-horse weeder, used for morning-glory control. Made by a blacksmith. (From Cir. 256.)

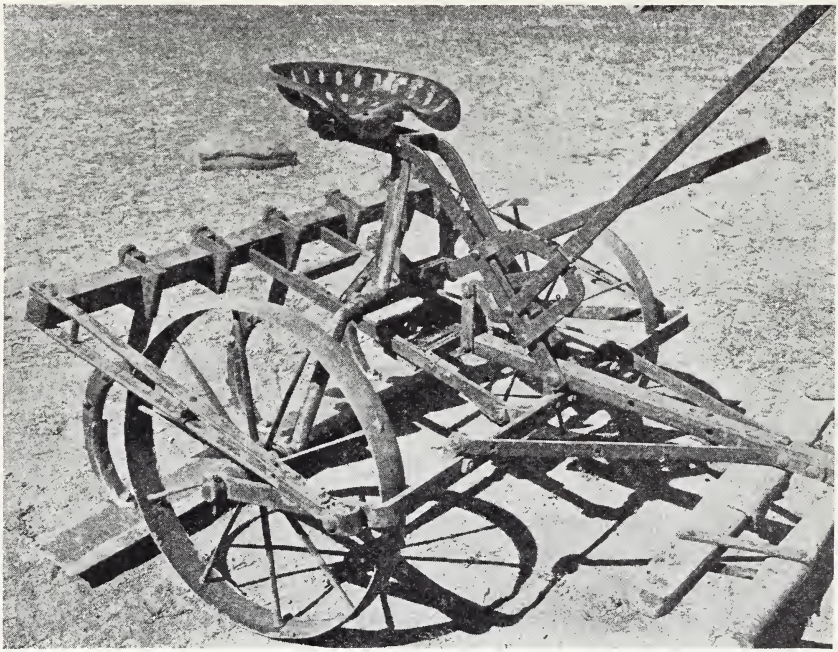

Fig. 23.—Two-horse weeder used for morning-glory control. The blade can be raised from the seat. (From Cir. 256.)

Control by Smothering.—Nonliving materials, such as tar paper and straw manure, when used to control morning-glory, by smothering have generally failed. Though tar paper, properly lapped, has proved effective for small areas, one must watch carefully to prevent the vines from growing out between the layers. The principle involved in smothering the plant with such materials is the same as in cultivation—namely, to prevent the formation of green leaves, thus forcing the plant to use up its reserve material in developing new shoots. Efforts to smother morning-glory with organic substances, such as straw and manure, have uniformly failed.

Cropping.—Of the crops used, a vigorous stand of alfalfa, well watered, is best and will greatly reduce, though not completely eradicate, the morning-glory. Experience shows that if the field is kept in alfalfa four or five years, morning-glory will be so reduced in vigor that other crops can be grown for several years before the weed renders them unprofitable. The use of alfalfa, followed by cultivation or by chemical treatment, will in the long run probably prove the most effective means of control.

Flooding.—In morning-glory control, flooding has been used with variable results. Where water is plentiful and cheap, it would warrant trial. The infestations should be diked and submerged for 60 to 90 days in midsummer. Where seeds are abundant in the soil, the area may be allowed to dry until germination starts and then reflooded for two or three weeks. Best results from flooding are apparently obtained on light or sandy soils.

Control with Chemicals.—The attempts to eradicate morning-glory with chemical herbicides have met with varying success because of insufficient knowledge as to the method of absorption of the chemical by the plant, and of the proper physiological and environmental conditions for absorption. Even yet, knowledge on some of these points is meager; but certain conditions of growth and environment are known to be necessary for success, as explained in a previous section (pages 27 to 30).

The chemicals most widely used and most likely to succeed on morning-glory are carbon disulfide, arsenicals, and chlorates. One arsenical is marketed under the trade name of "K. M. G." The nature and methods of application of these herbicides are given on pages 27 to 38.

Though the use of herbicides offers a promising means of eradicating morning-glory, as stated before good results cannot be obtained without due attention to the stage of growth, the condition of the plants, the nature of the soil, and the environmental conditions at the time the spray is applied. No single application of any chemical is likely to eradicate morning-glory completely. Chemicals now available, however, are

effective on small infestations; and their use, though expensive, is often justified in preventing the spread of the weed. At present the most satisfactory chemical methods are too costly for large areas. Until more reliable and cheaper ones are found, cultivation and cropping are more feasible for large-scale control.

JOHNSON GRASS

Johnson grass, first introduced as a forage plant, has become one of our worst weed pests. It is a prolific seeder and spreads vegetatively by underground stems as well. The first step toward control is to prevent spread by seed. To do this, cultivation, mowing, hand-cutting, or oil may be employed. Cultivation, if practiced, should not extend beyond infested areas, for portions of the roots may be carried to noninfested parts and thus spread the pest instead of controlling it. On rather inaccessible areas, such as fence rows and ditch banks, the use of "stove-top" or Diesel oil is probably cheaper, for the area can thus be covered in less time and with much better results than with any other method. In a few cases where Johnson grass was sprayed with oil during hot summer days, the oil penetrated the underground stem as deep as 8 inches and thinned heavy infestations more than 50 per cent. The number of sprayings depends largely upon the growing conditions. With abundant moisture and good soil, Johnson grass is more difficult to kill than under dry, unfavorable soil conditions.

Many different herbicides have been tried on Johnson grass. At present, the chlorates appear most promising. In California "Atlacide" (calcium chlorate) has possibly been used more widely than sodium chlorate. A solution containing 1 pound of chlorate to 1 gallon of water may be applied as a fine spray to plants in full bloom or in the soft-seed stage. Sodium chlorate may be used in solution, or dry as a soil treatment in the early winter. The dosage depends upon soil type and rainfall. Three pounds per square rod is a good average treatment. Plants treated with chlorates should not be mowed or burned immediately, but should be allowed to stand in the dry condition until the following spring, when they may be burned. On small areas Johnson grass is effectively treated with carbon disulfide. Careful grubbing, particularly in loose or sandy soil, is also a practical method if all rootstocks are removed and destroyed.

Johnson is often confused with Sudan grass, which it frequently infests. In fact, the State Seed Laboratory finds that many samples of Sudan grass seed examined contain this impurity. Johnson grass is readily distinguished from Sudan grass by the presence of rootstocks, which differ from roots in having joints.

CAMEL THORN

Camel thorn, a comparatively new pest in California, is confined to certain areas in Imperial, Riverside, Kern, Kings, Merced, Madera, San Diego, Tulare, Los Angeles, and Fresno counties. Being a pernicious weed, it has been strenuously fought in these limited areas. As the plant is browsed by animals, the seed has been spread great distances by the movement of stock.

This thorny, semiwoody plant, in addition to producing innumerable seeds, develops roots that may go to depths of 10 or 12 feet and spread laterally 25 to 40 feet in a single year, sending up new shoots the next spring.

In the ten counties where camel thorn has been found, nearly all areas have been treated either with carbon disulfide, with arsenic by the jar method, or by flooding. The carbon disulfide and flooding methods did not prove wholly satisfactory, because of excessive costs and lack of water. The jar method, which employs a 1 per cent solution of arsenic trioxide, was first tried in an attempt to kill plants growing in the ballast of railway roadbeds. On these areas carbon disulfide or flooding could not be used. Evidently the plants growing in the ballast originated from roots growing through the railroad grade. When several of these plants were treated with arsenic solution, not only shoots growing in the ballast were killed, but also shoots on the opposite side of the grade, a fact showing definitely that all these plants were connected by underground roots to the one treated.

In view of these results, 10,000 jars were obtained, and some 70 acres of rather solidly infested land were treated in Kern County. Plants were selected at random and placed in the jars. After 36 to 48 hours the jars were moved to plants that had not been affected. A season's experience has proved that best results can be expected if the plants are mature when treated.

The cost of this method proved to be much less than that of either the carbon disulfide or flooding. Rather large areas were treated in Merced and Kern counties at an average cost of $25 per acre. Carbon disulfide treatment under similar conditions averaged approximately $250 per acre.

RUSSIAN KNAPWEED

Russian knapweed was introduced into California about 1912 in impure sugar-beet seed or Turkestan alfalfa seed. Since then it has spread widely and now occurs in isolated areas throughout the state. A pernicious perennial, very similar in its habits to morning-glory, Johnson grass, and hoary cress, it spreads rapidly, especially where seeds and

portions of the underground parts are carried by cultivating tools. The spread by seed is somewhat less rapid than with many other weeds because the seeds are born in cup-shaped heads that do not open readily at maturity; ready dispersal by wind is thus prevented. The seed is readily collected by harvesting machinery, however, and is a common contamination in cereals and seed crops.

Russian knapweed is one pest that deserves the serious attention of Californians, for invariably it works great crop injury. The methods of control mentioned under perennials apply here. Acid arsenical spray (pages 27 and 32) and sodium chlorate have given promising results. Apparently Russian knapweed is more susceptible to chemicals than either wild morning-glory or hoary cress.

HOARY CRESS

Hoary cress, which appeared in the Pajaro Valley in California about 1907, seems to have come originally as an impurity in alfalfa and lawn-grass seed. Importations of impure alfalfa seed during the World War started infestations in many parts of the state. At present this weed is spreading rapidly and threatens to be a serious pest.

Hoary cress is a perennial that first appears early in the spring and often matures by the last of May. Its underground stems are even more persistent than those of morning-glory. Although it often fails to set viable seed, a good crop if produced will germinate well and survive even under adverse conditions. Hoary cress has been known to displace alfalfa. It has no feed value whatever.

Thus far, carbon disulfide has proved reasonably satisfactory, although it has sometimes failed. Sodium chlorate, under certain conditions, has also brought fair results. Applications of 4 pounds or more per square rod on adobe-clay soils have given promise when made in the early winter. As explained on page 33, the amount of rainfall following the application of the chlorate determines the depth of penetration. In some localities hoary cress has proved very susceptible to control by clean cultivation and can be held in check by this method.

WILLOWS

The banks of ditches, levees, and drainage canals often become overgrown with willows. Gradually encroachment of the plants will greatly reduce the carrying capacity of a waterway. Much money is spent in controlling willows, especially by hand cutting, which usually causes a thicker stand the next year and must be repeated annually.

Chemicals have been tried to some extent. Common salt is effective when applied in sufficient quantities—approximately 10 pounds to an

average-sized clump of willows. Usually the willows are so thick that a solid ground cover of the salt is necessary—about 250 pounds to each square rod, or 20 tons to the acre. In the few instances where the chlorates have been tried as a foliage spray, a root penetration on some of the plants was distinctly noticeable, and in some cases complete eradication has been obtained. The observations were made on plants treated with 1 pound of chlorate to a gallon of water. In one area, willows were largely eradicated by chlorates applied to the cut stumps. The willow growth was rather thick, and the individual plants varied in size. Two to 4 pounds to the square rod, applied dry in January, was effective. In this case, however, as in others, follow-up applications were necessary.

On small areas carbon disulfide is very effective. One to two cups injected around the roots of individual clumps will kill the root system.

In some districts tractor pulling of willows has proved effective and economical. The jar method, using a 1 per cent arsenic solution, has given fairly satisfactory results. Large containers are required so that several branches can be included.

BERMUDA GRASS

Bermuda grass, widely used as a pasture and lawn grass in the south, has now spread from these areas and rather generally infests the central and southern parts of California. Its ability to withstand heat and dry summer conditions makes it one of our worst pests.

Many chemicals have been unsuccessfully applied in attempts to control this weed. Though occasional treatments have been encouraging, most have failed. Heavy applications of chlorates in early winter have proved promising, especially on sandy soils. Wherever Bermuda grass infests ditch banks, roadsides, or noncultivated soil, sterilization of the soil, as described in a preceding section (page 38), is the best method. Crop rotation and clean cultivation have sometimes proved fairly successful. As this grass cannot withstand dense shading, a rotation system that includes a crop such as Sudan grass or cowpeas, or an intertilled crop, followed by grain and then a heavy seeding of alfalfa, is recommended. In some sandy soils dry-plowing in the summer, followed by harrowing and frequent cultivation is used.

KLAMATH WEED

The mode of introduction of Klamath weed into the northwestern part of California is obscure; but within 50 years after its first recorded appearance it has spread over approximately 100,000 acres. A common roadside plant of Europe, it is now present in several eastern states and in Washington, Oregon, and Idaho. In California it occurs in nearly

every county north of San Francisco Bay and in Santa Cruz County. Although its further spread southward will probably be limited by its requirement of rather moist conditions for optimum growth, there is still much territory available for increase in the north coast counties. Control methods, therefore, are highly desirable.

Klamath weed is a relatively shallow-rooted perennial, growing vigorously to a height of 1 to 3 feet during the summer. It tends to form an interconnected root system and grows so densely as to crowd out most of the common annuals of our ranges. It not only lacks forage value, but is toxic to certain breeds of sheep and cattle.

Noting the seriousness of this pest, the California Agricultural Experiment Station established in 1934 a field project to study its control and eradication. No definite report can yet be given upon this experimental work, which so far has taken the form of a comprehensive test of herbicides on the weed. A few significant points, however, should be helpful to those interested in chemical control.

Sodium chlorate, the chemical most commonly used on Klamath weed, is best applied in the spring when it will receive from 2 to 5 inches of rainfall after the treatment. Applied in this way, 1 pound of chlorate per square rod has killed all established plants so that the plots were covered with a heavy stand of grass by the following spring. New seedlings, however, were present; and, judging from experience with chlorates in the past, the areas will probably be reinfested within two more years. The effects of chlorate are not lasting enough to insure eradication.

If applied earlier in the season, so that more rainfall occurs afterward, up to 3 pounds per square rod is required for comparable results; and when subject to the total seasonal precipitation even this amount has been leached away without killing all the plants.

Borax, which is fixed more firmly than chlorate (page 42), will probably prove valuable in controlling Klamath weed. Applications of 4 to 8 pounds per square rod in February, 1935, gave excellent results. More tests, however, will be required before this material can be generally recommended.

Sodium arsenite has produced the most lasting results of any chemical tested and should be very useful. Applications equivalent to 4 pounds or more of As_2O_3 per square rod have given complete sterilization for two years. In this time all seeds in the surface soil should have germinated; and as grass returns these areas may remain clean.

All any chemical can do is to kill the established plants and prevent recurrence from seed previously deposited in the soil. Reinfestation from seed disseminated by grazing animals is an ever present problem. All movements of stock from infested to clean ranges should be avoided,

and a control program once inaugurated on a given range should be followed out rigidly until all infestations are eradicated. More work must be done before any suggestions can be made as to control on large infested areas. In such cases, obviously, chemicals are out of the question, for they would cost many times the value of the land.

Fig. 24.—Removing the seed stalks of artichoke thistle.

POISON OAK

Small infestations of poison oak can be grubbed out by an individual who is immune. In some cases fair results have followed spraying with Diesel oil. One spraying usually kills the top growth; and although there may be some regrowth later in the season, as a rule a second spraying eradicates most of the plants. If regrowth follows, a third spraying with oil may be necessary. Oil applied to the stumps of cut plants is also effective.

A little chlorate solution (see page 32) applied around the roots of each plant will usually give a satisfactory kill. Roots of other plants interlaced with the poison oak will be killed also. If poison-oak plants are burned, care should be taken to keep out of the smoke, which carries the volatile oil that causes injury.

ARTICHOKE THISTLE

This weed has infested approximately 70,000 acres of grazing land in Solano County. Scattered areas occur in Contra Costa, Alameda, Napa, and Orange counties. Particularly in the Bay region, environmental conditions favor its rapid spread. A tall perennial from a rather shallow crown, it produces an abundance of seeds. Although oils, chlorates, and

sulfuric acid have been tried as herbicides, the most practical method of eradication is grubbing. Individual, scattered plants may be removed with a grub-hoe (fig. 24) ; and heavy infestations are plowed out with a special tractor-drawn implement equipped with a heavy blade (fig. 25). The cost of this latter operation has averaged from $8 to $10 per acre,

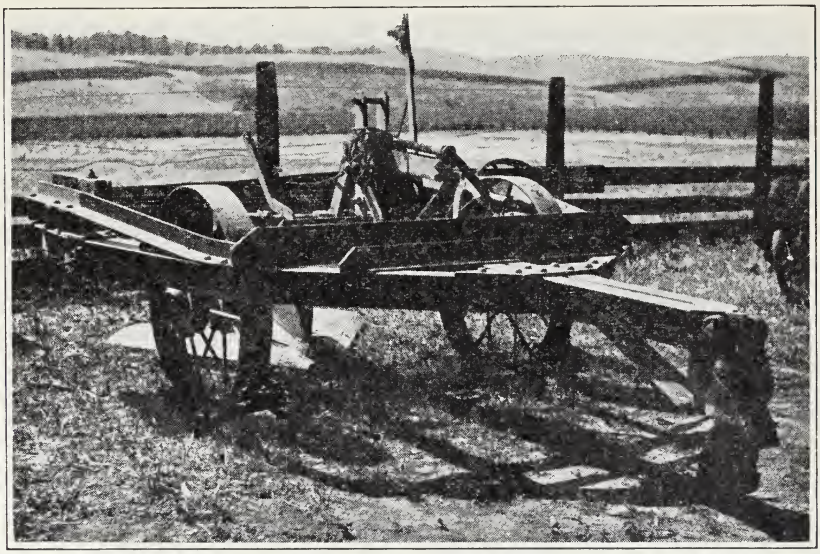

Fig. 25.—Equipment used in plowing out artichoke thistle.

according to the roughness of the area. If the weeds are growing on slopes too steep to plow, treatment with oil is the cheapest control method. Just before the growth of the seed stalk, about ½ pint of Diesel oil is applied to the crown of each plant. The cost of this treatment varies greatly with the terrain and the degree of infestation.

REGULATORY PHASES OF WEED CONTROL[14]

When, despite general recognition that a particular agricultural pest needs control or eradication, a few persons neglect their responsibility and do not take the advisable steps, there arises a demand for laws and regulations to compel the negligent to coöperate.

Laws for weed control when necessary should meet three needs: (1) they should prevent introduction of any new and seriously noxious weed pests; (2) they should authorize responsible official agencies to eradicate any new or limited infestations; and (3) they should provide for the abatement of any noxious weeds against which there is continual

[14] This section was prepared by W. C. Jacobsen, Supervisor of Rodent and Weed Control, State Department of Agriculture, Sacramento.

or active warfare and against which recalcitrants do not take the necessary steps.

Certainly plant quarantine as a preventive measure should constitute a primary phase of weed suppression. Federal recognition of this need should precede that of the state or county. So far, dodder seems to be the only weed pest that has claimed federal attention. If noxious weeds are to be ignored in seed shipments from other nations, and if the apparent policy of allowing a tolerance of weed seeds in such importations is not modified, American agriculture is faced with a continuous hazard, and we shall ever have camel thorn and Russian knapweed cases with which to cope. Another very important means of acquiring undesirable plant immigrants is through new plant introductions. A plant or shrub seemingly of value for ornamental or even forage purposes may develop noxious tendencies in a new environment.

Our immediate concern, however, is this: What has California accumulated in the way of regulatory measures affecting noxious weeds? History shows that a new country must look to outside sources for seeds and planting stock. Of course, weeds are sure to be stowaways and will land unless detailed inspection is provided. A country with wide divergences in climate and soil offers a fertile field for establishment of weeds. When large land holdings were the order, weeds were usually taken as necessary evils. Should one field become abnormally weedy, it was not difficult to transfer operations to another.

Apparently the first law affecting weed control was passed by the legislature in 1903 and was specifically directed against Johnson grass. Since then more specific authorities have been added.

Obviously, not every weed could be considered noxious, for some were reasonably desirable as covercrops. If we ignore the rôle of such covercrop weeds in harboring injurious insect pests and plant diseases detrimental to commercial plantings, we might say they were beneficial. Hence, one of the original and practical necessities was a sound definition of a noxious weed. This point apparently took years of study; the 1929 legislature first enacted the authority to consider as "noxious" any plants or seeds detrimental to agriculture. With the enactment of the Agricultural Code in 1933, the definition of a weed was broadened to include "any form of vegetable life" that is, or is apt to be, dangerous, or detrimental, to the agricultural industry of the state; and as such is included in the definition of a "pest." (Sec. 100, Agricultural Code.[15]) Undoubtedly, the court must ultimately decide whether or not a particular weed belongs in the category of pests which the Code declares

[15] Published in pamphlet form by the California State Department of Agriculture, Sacramento.

to be public nuisances. Those generally concerned with the problem of weed control or eradication, however, understand what this term really means, and regulatory officers will be able to substantiate their determinations by evidence in the event that a weed "pest" is involved in court proceedings.

There are actually available now in California laws, mainly in the Agricultural Code, the following authorities and provisions relative to weed control which are apparently operative. They are segregated to show how they may be responsive to the three needs previously noted.

To Prevent the Introduction and Spread of Noxious Weeds.—(*a*) The quarantine authority available to the Department is applicable to prevent the introduction of weed pests just as it is against injurious insects, plant diseases or pest animals involved in interstate shipments. However, if the consignee can eliminate weed seeds by cleaning or crushing, then the shipment may be released. (Sections 105, 106, 115, and 116, Agricultural Code.) The use of this authority is limited since in most instances weed infestation is capable of determination upon inspection.

(*b*) Section 124 of the Agricultural Code reflects the same authority for the rejection of weed-pest-infested shipments moving intrastate as pertains to other agricultural pests. The alternative procedures in this section will permit release after cleaning.

(*c*) Section 125 of the Agricultural Code provides that if anything originating in another county or locality of the state or in another state or foreign country is found upon inspection to be infested with the *seed* of any pest not of common occurrence at destination, the Director or the agricultural commissioner shall notify the owner or bailee of the shipment to return it within 48 hours, provided that if the seeds can be destroyed by a treatment the shipment may be released.

(*d*) Section 128 of the Agricultural Code gives authority to hold, after written notice, any commodity found to be actually weed infested on the premises where the commodity is encountered until it is cleaned of the "pest" to the satisfaction of the county agricultural commissioner or the Director of Agriculture.

(*e*) The weed-free area provisions of the Agricultural Code make it unlawful to transport, into the district proclaimed by the Director, the seeds of any specific weeds for which the weed-free area has been declared.

Eradication of Limited Infestations.—(*a*) The general pest-abatement provisions of the Agricultural Code are available for *eradication* procedure but are advisable for eradication only on limited infestations of the more serious kinds or for newly introduced noxious weeds (Sections 129–138, Agricultural Code.)

(*b*) The weed-free area provisions, sections 155 to 158 inclusive, make it unlawful to permit any weed named in a weed-free-area proclamation to continue to propagate itself or mature seed.

(*c*) A section of the Code which is in effect a special law is directed to the eradication of camel thorn. (Sec. 159, Agricultural Code.)

(*d*) Austrian field cress is the subject of special eradication authority. (Sec. 159*a*, Agricultural Code.)

(*e*) The Director of Agriculture may enter into coöperative agreements with boards of supervisors and other official, state, and federal agencies for the purpose of eradicating pests dangerous to the agricultural industry of California. (Sec. 34, Agricultural Code.)

(*f*) The board of supervisors may authorize county agricultural commissioners to enter into contracts with landowners for the eradication of "pests." (Sec. 149, Agricultural Code.)

(*g*) An area of limited infestation of a particularly serious and injurious weed pest can, if necessary, be circumscribed by quarantine lines to aid in eradication or prevention of spread. (Sec. 108, Agricultural Code.)

General Abatement Procedure Against Weed Pests.—(*a*) The general abatement provisions of the Agricultural Code, sections 129 to 138 inclusive, provide for the service of abatement notices wherein the owner of infested property is notified to eradicate, control or destroy the "pest" within a specified time. If not done by him, then the county agricultural commissioner has authority to proceed, the cost of such abatement, if not paid by the owner, becoming a lien on the property. This is applicable where general weed-control programs as to particular weeds are in effect and where there are negligent property owners or recalcitrants who must be required to clean up. This phase of abatement is also applicable to publicly owned or controlled areas subject to the jurisdiction of the governing board of a political subdivision of the state.

(*b*) The governing board of a county may declare a particular weed growing upon streets or sidewalks or even on private property a public nuisance. Under this authority the county agricultural commissioner or the County Board of Forestry, or some other officer, board, or commission designated by the supervisors is authorized to post notices requiring abatement. If the owner fails to act, abatement may be proceeded with by the officer posting the notice and the costs included with the annual tax bill. (Chapter 457, Statutes 1929.)

(*c*) Under the general permanent powers of boards of supervisors, authority is given to provide for the destruction of noxious weeds. (Subsection 3, section 4041.11, Political Code.) This authority is generally exercised through the passage of county ordinances.

(*d*) "Maintenance" as defined in the new Streets and Highways Code includes "weed control" as one of the general utility services thereunder. (Sec. 27, Streets and Highways Code.)

(*e*) There are general law provisions applicable against public nuisances.

Incidental to the above specific references, there is authority in the pest-abatement sections of the Agricultural Code that materially assists in the case of canals and ditches which are not subject to the jurisdiction of any political subdivision, special provision having been made for the service of abatement notice upon the users of water from such ditches and making them responsible for weed cleanup. Lacking response from them, the commissioner is allowed to proceed, the users being jointly responsible for the costs.

Specific authority is to be found in the Irrigation District Improvement Act, which authorizes the organization of improvement associations for weed-control purposes.

The seed inspection provisions of the Agricultural Code are directed primarily to the prevention of introduction of certain primary and secondary weeds through the planting of impure seed. (Sections 911 to 920 inclusive, Agricultural Code.)

There are still a few important needs in connection with regulatory measures affecting weed control; namely, improved federal regulations to prevent the introduction of seeds of injurious weeds in plant shipments and in imported commercial seed from foreign countries; an improvement in seed inspection laws, both federal and state, tending toward the elimination of a permissible tolerance, since even one viable noxious weed seed may start an infestation; and, further, for the guidance of enforcement officers, basic research inaugurated or intensified by agencies such as the United States Department of Agriculture, coöperating with state experiment stations, in some such manner that enforcement officials can devote a full share of their time to eradication or control work and not be burdened with investigation.

Above all, the dissemination of sound information to aid and encourage the recognition of the importance of weed control is vital to the proper application of regulatory measures.

No matter how well conceived and elaborately stated our regulatory measures, they cannot be fully and effectively administered unless public sentiment is in thorough accord with their application and enforcement.

SENDING WEEDS FOR IDENTIFICATION

As this circular does not deal with classification of weeds, the individual is encouraged, when in doubt, to send in weed specimens for identification. One should know the specific weed in order to plan the best program for its control. Very often weed specimens sent in by growers are so framentary, so incomplete, or so poorly packed, that they cannot be identified with certainty. The leaves, flowers, and fruits, and a portion of the root system should always, if possible, be included in a specimen. In certain families of plants, such as the mustards and carrots, the mature fruits are frequently needed for identification. In other families, such as grasses, the underground structures may be necessary. In any event, include flowers as well as leaves, for of all plant structures the flowers are the most useful in making an identification. Also helpful is a brief description of the growth habit of the weed, including its height, and the conditions under which it grows.

Specimens should be wrapped in moist paper, moist cotton or cloth, or moist moss, and enclosed in a box or heavy paper wrapping. Or they may be pressed between several thicknesses of newspaper, or between folds of blotter paper or soft corrugated cardboard, and mailed in a thoroughly dry condition. Material simply placed dry in an envelope or box, usually arrives in such poor condition that it cannot be used for determination.

Send specimens for identification to any of the following agencies: County Agricultural Commissioner; County Farm Advisor; State Department of Agriculture, Bureau of Rodent and Weed Control, Sacramento; Department of Botany, University of California, Berkeley; or Division of Botany, University Farm, Davis.

COMMON AND SCIENTIFIC NAMES OF WEEDS REFERRED TO IN THIS CIRCULAR

Alkali mallow.....*Sida hederacea*
Arrowhead.....*Sagittaria latifolia*
Artichoke thistle....*Cynara scolymus*
Austrian field cress..*Roripa austriaca*
Barnyard grass..*Echinochloa crusgalli*
Beggar-ticks.....*Bidens frondosa*
Bermuda grass.....*Cynodon dactylon*
Black bindweed *Polygonum convolvulus*
Blessed thistle.....*Cnicus benedictus*
Broad-leaf plantain...*Plantago major*
Brome grass.....*Bromus* spp.
Buckthorn.....*Amsinckia* spp.
Bulrush.....*Scirpus occidentalis*
Bull thistle.....*Cirsium lanceolatum*
Bunch grass.....*Sporobolus airoides*
Bur clover.....*Medicago hispida*
Burdock.....*Arctium minus*
Camel thorn.....*Alhagi camelorum*
Canada thistle.....*Cirsium arvense*
Cattail.....*Typha latifolia*
Cat's-ear.....*Hypochaeris* spp.
Cheat.....*Bromus secalinus*
Chess.....*Bromus secalinus*
Chicory.....*Cichorium intybus*
Chickweed.....*Stellaria* spp.
Cocklebur.....*Xanthium canadense*

Common spikeweed. *Hemizonia pungens*
Corn cockle..... *Agrostemma githago*
Crab grass... *Syntherisma sanguinalis*
Creeping buttercup. *Ranunculus repens*
Creeping mallow ..... *Sida hederacea*
Curled dock..... *Rumex crispus*
Dandelion..... *Taraxacum officinale*
Death camas .... *Zygadenus venenosus*
Dock ..... *Rumex* spp.
Dodder ..... *Cuscuta* spp.
Doorweed..... *Polygonum aviculare*
Dyer's woad..... *Isatis tinctoria*
Fiddleneck..... *Amsinckia* spp.
Field madder..... *Sherardia arvensis*
Foxtail ..... *Hordeum* spp.
Hoary cress..... *Lepidium draba*
Jimson weed..... *Datura stramonium*
Johnson grass..... *Sorghum halepense*
Klamath weed. *Hypericum perforatum*
Knotweed..... *Polygonum aviculare*
Lamb's-quarters.. *Chenopodium album*
Larkspur..... *Delphinium* spp.
Lupine..... *Lupinus* spp.
Marlahan mustard .... *Isatis tinctoria*
Mayweed..... *Anthemis cotula*
Milk thistle..... *Silybum marianum*
Morning-glory..... *Convolvulus* spp.
Napa thistle..... *Centaurea melitensis*
Nightshade ..... *Solanum* spp.
Nut grass..... *Cyperus rotundus*
Nut sedge..... *Cyperus rotundus*
Oxalis..... *Oxalis* spp.
Pigeon grass.... *Chaetochloa lutescens*
Pigweeds..... *Chenopodium* spp.
Poison oak..... *Rhus diversiloba*
Prickly lettuce..... *Lactuca scariola*
Prickly pigweed *Amaranthus retroflexus*
Prostrate pigweed *Amaranthus blitoides*
Puncture vine ..... *Tribulus terrestris*
Purple star thistle. *Centaurea calcitropa*
Purslane..... *Portulaca oleracea*
Ragweed ..... *Ambrosia psilostachya*
Red rice..... *Oryza rufipogon*
Red stem..... *Ammannia coccinea*
Russian knapweed... *Centaurea repens*
Russian thistle.....
Salsola kali var. *tenuifolia*
Sandbur..... *Cenchrus pauciflorus*
Scale grass.... *Leptochloa fascicularis*
Seaside heliotrope.....
Heliotropium curassavicum
Sedge..... *Cyperus* spp.
Shepherd's purse.....
Capsella bursa-pastoris
Sour clover..... *Trifolium fucatum*
Sow thistle..... *Sonchus* spp.
Spike rush..... *Eleocharis palustris*
Speedwell..... *Veronica* spp.
Spiny sow thistle..... *Sonchus asper*
Spotted spurge... *Euphorbia maculata*
Sprangle-top .. *Leptochloa fascicularis*
St. Johnswort.. *Hypericum perforatum*
Sunflower ..... *Helianthus* spp.
Tall marsh elder..... *Iva xanthifolia*
Tall pigweed.. *Amaranthus retroflexus*
Tocalote ..... *Centaurea melitensis*
Tule ..... *Scirpus* spp.
Tumbleweed... *Amaranthus graecizans*
Umbrella plant..... *Cyperus* spp.
Water grass.....
Echinochloa crusgalli (and varieties)
Water hemlock..... *Cicuta* spp.
Water hyacinth... *Eichornia crassipes*
White horse nettle.....
Solanum elaeagnifolium
Whorled milkweed. *Asclepias mexicana*
Wild aster..... *Aster* spp.
Wild blackberry ..... *Rubus* spp.
Wild garlic ..... *Allium vineale*
Wild hemlock ..... *Cicuta* spp.
Wild mustard ..... *Brassica* spp.
Wild lettuce..... *Lactuca pulchella*
Wild oats ..... *Avena fatua*
Wild onion..... *Allium* spp.
Wild radish ..... *Raphanus sativus*
Willow..... *Salix* spp.
Wood sorrel ..... *Oxalis* spp.
Yellow star thistle.....
Centaurea solstitialis
Yellow water weed. *Jussiaea californica*

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